DRAINAGE PROBLEMS OF THE EAST.

BY

C. C. JAMES.


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SALUS GENERIS HUMANI.

Drainage Problems of the East

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Being a Revised and Enlarged Edition of "Oriental Drainage"

By

C. C. James

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FOREWORD.

I HAVE been asked to supply a brief introduction to a new and enlarged edition to a work which, like its author, is really in no need of an introduction to any one acquainted with the recent development of sanitary engineering in the cities of the East. Mr. Carkeet James has had the best of all training as an instructor of his profession in the treatment of the multifarious problems that claim solution in oriental urban areas. His long experience in the service of the Municipal Corporation of Bombay would by itself supply credentials for the task which he has undertaken in writing this book. A city with a population of nearly a million inhabitants, ruled by a Corporation bent upon living up to the high standard of local administration implied in its claim to be "the first city in India," makes demands which severely test the scientific and practical capacity of those who have a responsible part in promoting its sanitary well-being. The conformation of the Island of Bombay, the slight gradient in some parts and the entire want of gradient in others have presented to the drainage engineers who have attacked its drainage problem difficulties of no common order, and a practitioner, who have been long engaged in bringing a work of that nature to a successful issue, may claim to have learnt much in that best of schools—practical treatment of the constructional side of a great drainage undertaking, and prolonged supervision of the scheme when at work. As one who lived in Bombay during the greater part of Mr. Carkeet James' service in that progressive city, and who had opportunities of judging of the Corporation's success in carrying out its great drainage policy, it gives me pleasure to commend to so many of the engineering profession as may be interested in sanitary construction in the East a new edition of a work which has already earned widespread approval.

Mr. Carkeet James' experience in designing and executing the main drainage of the city of Cairo belongs to a later period in his career. The work has met with the unqualified approval of the Egyptian Government, and gives additional authority to the counsels which in this later edition of his text book he has placed at the service of those of his brethren who may be called upon to undertake similar work in the cities of the East.

It may seem a commonplace to remark that the principles of engineering science are the same no matter in what part of the world they may have to be applied. But this truism needs to be interpreted in the light of varied local conditions. In the East the sanitary engineer has to confront factors peculiar to the scene of his operations, and relating to material, labour, meteorological phenomena, not to forget social and religious prejudices, sometimes of an uncommonly perplexing nature. To be able to solve satisfactorily all the "Drainage Problems of the East," an engineer must have lived for the best years of his life in the East, and have handled them *in situ*. That he has done this in India and in Egypt will be recognized to be not the least of Mr. Carkeet James' qualification for advising upon the important subjects treated in this book.

T. J. Bennett.

Harwarton, Speldhurst,
February, 1916.

PREFACE.

THE favourable reception that has been accorded to my *Oriental Drainage* by the profession and the Municipal and Sanitary Authorities, as well as by a large section of the general public encouraged me to contemplate the issue of another edition. In making preparations, however, with that object in view, I found that there was so much new and valuable matter of a practical and interesting nature that might with advantage be included in a new work, and that the original volume was susceptible of considerable expansion in order the more thoroughly to extend the scope of the work, that nothing short of a new book would meet the requirements of the subject. The many changes thus involved in the extent and nature of the original work have caused me to adopt the name *Drainage Problems of the East* in order to distinguish the present work from its predecessor, from which, though fundamentally similar, it differs very much both in its scope and in its text, as well as by the plans and illustrations which forms, I hope, not its least interesting feature.

Apart from the bringing up to date and expansion of the Chapters taken from the original work, new Chapters have been added, dealing with such highly instructive drainage-systems as those of Karachi, Calcutta, Rangoon, Singapore, Penang, Shanghai, and Alexandria, which cover a wider geographical area, as well as with sanitary conditions in other Eastern countries, and with some of the more important enterprises that have been undertaken in recent years in India and the Far East.

The development of the use of Septic Gas has also been fully dealt with, and with it the more recent experiments in regard to the biological treatment of sewage have been described.

New Appendices have been added, one dealing with useful and

short specifications connected with sanitary matters, and the other giving a description of the Hydrolytic Tank designed by the eminent experts Dr. Owen Travis, M.D., M.S., Barrister-at-Law, and Mr. Edwin Ault, C.E.

I have to express my thanks to Mr. N. Maughan, M.I.C.E., and my Assistant Mr. Dinshaw D. Daruvala, A.M.I.C.E., L.C.E., who have given me much valuable help in the compilation of this work.

C. CARKEET JAMES.

1906.

PREFACE TO SECOND EDITION.

The first edition of "Drainage Problems of the East" has been sold out for some years, and the Publishers have on several occasions asked for a second edition.

But since 1906 the Author has been so fully engaged on large Drainage Works in Egypt that it has been impossible to even consider the matter.

The war however has brought some enforced leisure, and the Author has in this edition endeavoured to bring the latest sanitary information up to date.

Sanitary Science has made considerable strides since 1906. Certain works described in the earlier edition, and in progress then, have been completed, and these have been dealt with.

Several drainage schemes in Egypt have been described, notably Cairo; the latest information in regard to profitably dealing with sludge has been given, and a new chapter devoted to it.

Certain obsolete matters have been deleted, and new Appendices have been added.

The Author desires to express his thanks to his partner Mr. Michell Whitley, M. Inst. C. E., for the great help he has given, and for the interest he has taken during the revision of this work, and to others referred to in the letterpress.

C. Carkeet James.

Broadway Court, Westminster,
London, S.W., 1917.

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PART I.

DRAINAGE PROBLEMS OF THE EAST

CHAPTER I

Drainage Systems

UNTIL comparatively recent years, open drains at the sides of streets, that depended on the monsoon rains for their annual cleansing, constituted the only drainage system existing in many important Indian cities and towns, and no serious attempt had ever been made to deal effectively with the drainage of such areas.

By the passing of Municipal Acts, Government created local authorities with full powers to deal with the sanitation of their respective towns, and to compel the people themselves to adopt such sanitary measures as might be considered necessary for the general welfare of the inhabitants. It is, however, only of late years—owing chiefly to the ravages of cholera, plague, and other diseases in some of the largest urban areas—that these local authorities have realized their responsibilities in the matter, and that the people generally have awakened to a sense of the comfort and the benefits derivable from modern sanitary measures. The result has been that most of the larger cities and towns are now provided, or are about to be provided, with some modern arrangement for the disposal of their sewage, combined with a plentiful water supply.

Hand Removal or Conservancy System.—One of the earliest attempts of Municipal Governments to deal with the sewage of towns was undoubtedly that of "hand removal," or as it is frequently named the "conservancy system." This

system still exists in many places possessed of no proper plan of drainage.

Under the conservancy system, all night-soil, etc., is collected in vessels and deposited in local cess-pools provided for the purpose: the cess-pools are emptied periodically, the fœcal matter being carried away to some convenient site outside the inhabited area and buried in the ground, while the sullage is usually left to soak into the ground.

There can be no question that this method is both objectionable and insanitary, in view (a) of the non-removal of sullage and fœces for several hours from the vicinity of buildings, (b) of the passage of sullage and night-soil carts through densely inhabited streets, and (c) of the emptying of these carts at various depots, and the consequent liberation of a large collection of offensive and dangerous gases. But the method is preferable to allowing refuse and filth of every description to putrify in the open air, and it is not every town that can afford to adopt a more modern method for the disposal of its sewage.

For use in connection with the working of the "conservancy system," many good types of privies for the houses of the poor have from time to time been designed. Illustrations and descriptions of some of these are given in Chapter III.

Of the regular drainage systems followed, there are two kinds, known as the "combined" and "separate." The "combined system" is that in which all the sewage, stormwater, etc., is carried through one sewer. It is rarely applicable to Eastern countries, in which the seasons are well defined and the rainfall concentrated in practically only four months of the year, for the reason that, where the rainfall exceeds 30 inches, no sewers have as yet been designed that are at once capable of being self-cleansing in the dry weather, and large enough to carry the surface water during the monsoon period. Sewers of larger construction than are necessary for the sewerage proper, soon become charged with deposit in the dry weather and may thus prove highly injurious to health.

The "separate system" is that in which separate drains are provided for the sewage, the surface water, and occasionally the subsoil water. This system, though more costly than the "combined system," has three distinct advantages, namely: (a) smaller sewers can be used, (b) the formation of sewer gas is minimised, and (c) greater facilities are afforded for supervision and cleansing.

The Author's experience leads him to prefer carrying the subsoil and surface water in one drain, and all sewage, and such rain water as falls on small court-yards and sweepers' passages or gullies, in a separate sewer; and in spite of its extra cost, he believes this system to be generally the best suited to Eastern countries, in which the rainfall is confined to a few months in the year. No hard and fast rule for the adoption of any one system can, however, be laid down; the ultimate verdict must rest upon the fullest consideration of local conditions.

When once it has been decided which system should be adopted for the drainage of any area, a very careful study of the ground and its natural drainage should be undertaken, in order that the best alignment for the main sewers may be accurately determined and the most convenient and economical site chosen for the sewage outfall or place of discharge for final disposal.

Gravitation.—Sewers discharging wholly by gravitation into a river or sea are an ideal feature of any drainage system. In practice, however, the ideal is rarely attainable; and it will generally be found necessary to lift the whole or a portion of the sewage of a town, either by pumping or other means, before it reaches its outfall and is finally disposed of.

The greatest care must, therefore, be bestowed upon fixing the gradients of sewers, it being always remembered that too steep a gradient is quite as undesirable as too flat a gradient. If it be too steep, the inner surface of the sewer is liable to corrosion, and, if too flat, a precipitation of solids, with consequent troubles and difficulties, ensues.

Every sewer, of whatever size or shape, has its own minimum self-cleansing gradient, and such gradient should be looked upon as a essential, and on no account to be reduced, even at the cost of additional lift.

Pumping.—Where a town is so situated that the whole of its sewage will gravitate to one point, but at too low a level to admit of a free discharge, the lifting of the sewage would best be effected by direct acting pumping engines. But gravitation to a single point is frequently an impossibility ; and in such cases the town should be divided into sections, the sewage of each section, wherever necessary, being automatically lifted by one of the following methods, *viz.*,

(a) Air pressure, known as the Hydro-Pneumatic System ;

(b) Water pressure, known as the Hydraulic System ;

(c) Electricity, known as the Electrical System.

The most economical type of engine for pumping installations requiring not more than 25 brake horse power, is probably an oil or gas engine connected by gearing to a two or three throw vertical ram pump, with externally packed plungers. If higher power be needed, steam is generally preferable on account of its great adaptability to a varying load. If an oil engine be selected, one of the several types, which are adapted for burning the lowest grade of bulk kerosine oil, should be chosen, not only by reason of the greater economy of this oil, but also of its universal distribution amongst the marts and bazaars of the East.

For high or even moderate lifts, where the pumps have to be placed below ground level, there is a choice of the beam, the marine or other types of vertical engine, of which the Worthington is a good example, coupled direct to the pump below, or of horizontal engines connected to the pumps through the medium of a bell crank placed in a frame above the pump well.

For low lifts, the Worthington direct-acting horizontal pumping engine, or a centrifugal pump, coupled direct to a high speed horizontal or vertical engine, is suitable ; but the latter is not to

be recommended for sewage pumping unless the total lift is less than 25 feet, for although its initial cost is cheap, its efficiency is low.

Vertical ram pumps are subject to less wear than horizontal pumps, as grit, which is always a special trouble in the East, does not lodge so readily on the moving parts of the former. Pumps of the bucket and plunger type are not as suitable as ram pumps for pumping sewage, on account of the excessive wear caused by grit between the bucket and the pump barrel. The valve area in a pump of this type is also necessarily very restricted—a very undesirable feature where sewage is to be pumped. With ram pumps the valves can be so arranged as to be entirely independent of the ram, and can thus be made of sufficient area.

Now that an apparently unlimited supply of Petroleum Liquid Fuel is obtainable in both the Eastern and the Western Hemispheres, it will probably be rapidly adopted, in preference to coal, by Municipalities for use in Pumping Stations situated within and beside large cities. By its use the nuisance of dust, smoke, soot, and ashes is, with ordinary care, entirely obviated—an important consideration to Municipalities, whose duty it is to set an example in such matters. Liquid Fuel is composed of a variety of substances, among which crude or semi-crude Petroleum, or the residue of Petroleum after refinement, chiefly figures. Its flash point ranges from 150° to 210° Fahrenheit, and its calorific value as compared with coal ranges from $1\frac{1}{2}$ to 1 to about 2 to 1. About $1\frac{1}{10}$ pint of oil is required per horse power hour.

Pneumatic System.—Local circumstances often require the sewage from several sections of a City to be lifted or pumped, while the major portion of the sewage may have a natural outfall. In such cases, the Pneumatic Ejector System is very suitable. In this system the motive power is compressed air, carried in small pipes to various points and there utilized for the required purpose. The system can also be applied when the whole of a town's sewage has to be lifted, and special advantages are claimed in this contingency; but in such circumstances it would probably be more

economical to adopt direct pumping, except in cases where the sewage has to be lifted at several points.

The following are the advantages claimed for this system :—

(1) The interception of the bulk of the sewage at higher levels, and consequent saving of power as compared with a single pumping station in which the whole has to flow down to the lowest point, the continued fall to the pump ing station being so much absolute waste power.

(2) The entire severance of each district from the main collecting sewers and the rest of the drainage area. Thus in the event of any epidemic disease breaking out in one district, it cannot be conveyed by sewers into healthy districts, as is often the case when the whole area is connected by a network of drains leading to a common outfall.

(3) The avoidance of deep cuttings and of large sewers, whereby great economy in initial cost is effected.

(4) The ready extension of the system in proportion as the population and occupied area increases, thus avoiding the immediate provision for probable future requirements, and relieving the ratepayers of the present day of the heavy burden of providing prematurely for the wants of a possible future population.

It should be mentioned what, at any rate in the East, is a very important advantage in connection with this system, and that is the automatic working of the ejectors. Where skilled labour is rather the exception than the rule, this must be counted a distinct advantage. Once an ejector has been placed in working order, it requires little or no supervision, and its inspection once a day is usually sufficient. Cases have been known where ejectors have worked for months without requiring any attention.

Fig. 1 illustrates a sectional view of the latest pattern ejector.

These ejectors consist of spherically ended cast or wrought iron containers, varying in capacity from 50 gallons upwards, and were until recently, solely manufactured by Messrs. Hughes and Lan-

caster, of London, but they are now obtainable from several makers. Messrs. Hughes and Lancaster have since 1880 successfully carried out upwards of 500 installations of this system of drainage in various parts of the globe. In Bombay they have been fixed in some districts in brick chambers and in other districts in cast

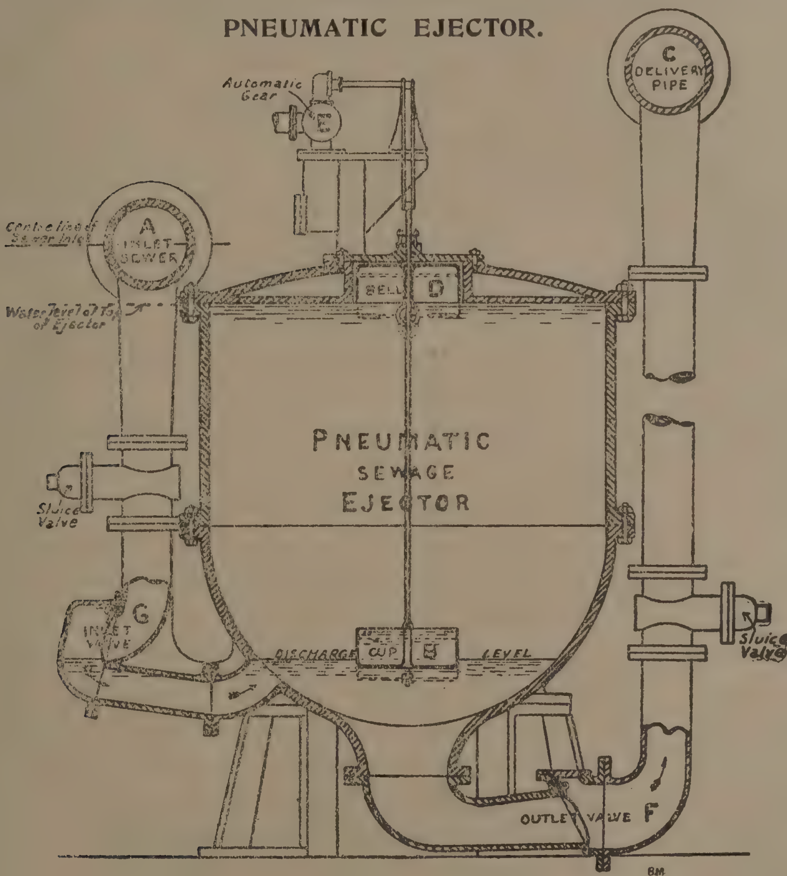


FIG. 1.

iron tubbings as shown in Plate 1. There are in this City several working with capacities varying from 100 up to 1,200 gallons each. The working of the ejectors is very simple. The sewage enters by gravitation through pipe A (Fig. 1), passes the flap G.

and rises in the container until the air within bell D is sufficiently compressed to lift the rod and cup B and open the valve E, which is connected with an air pressure main. As soon as the air is admitted from the pressure main, it is free to act on the surface of the sewage in the container. The pressure so applied closes the inlet valve G and forces the sewage out of the container past the outlet flap valve F into the pipe C and then into the sealed sewage main, through which it is forced to its outfall. The weight of the sewage retained in the cup B is sufficient, when the sewage in the container falls below the bottom of the cup, to close the pressure main valve E and to open an exhaust valve, through which the compressed air in the container escapes. As the air pressure is being exhausted, the height of the sewage in the sealed main C closes the flap F, when the container begins to refill. This process is repeated automatically so along as any sewage flows out of the inlet sewer A.

The compressed air required for the working of this system having been generated at some convenient central station is conveyed to the ejector in iron or steel pipes, laid under the ground at a depth of some 3 feet, where they are free from all danger of breakage by traffic and steam rollers.

The advantages of an ejector may be summed up as follows :—

(1) The working parts are reduced to a minimum and such as are requisite are not likely to get out of order.

(2) The parts with which sewage comes in contact contain no machine-tooled surfaces, which are unavoidable in pumps and get rapidly destroyed by the action of sewage, sludge and grit from the road detritus, etc. In the ejectors there is nothing but the hard skin of the original castings, coated with Dr. Angus Smith's composition, upon which the sewage can produce no detrimental effect.

(3) The friction of a pump piston and other working parts is avoided, the compressed air itself acting direct upon the fluid, without the intervention of any machinery,

and forming an almost absolutely frictionless and perfect piston, past which there can be no slip or leakage.

(4) The cup-and-bell float arrangement is one that cannot possibly get out of order, as an ordinary rising and falling float would be likely to do.

(5) The only tooled parts are those in connection with the small automatic air valve; this makes only one movement of two or three inches for each discharge of the container of from 50 to 1,200 gallons (according to the size of the ejector), and is only in contact with the compressed air and out of reach of the sewage.

(6) The sewage inlet and outlet valves are so arranged as to give a free passage way of the full area of the pipe to all solids that the pipe itself can carry. No part of the container has any depression or traps wherein solid matter can collect.

(7) The outlet is from the bottom of the ejector so that the whole of the sewage, including solids, sludge, grit, and everything brought down the sewer, is discharged out of the ejector.

(8) For these reasons no screening or straining of the sewage is necessary, as is the case with pumps, and the great nuisance caused by the cleaning of pump gratings and sump wells is avoided.

(9) The sudden rush of the whole contents of the ejector, when the discharge is into a main gravitating sewer, forms a most effective flush.

(10) The ejector forms an absolute severance of the sewers of each district from the main sewer.

The size of an ejector required for any district is determined by the estimated quantity of the sewage of the district, its capacity being equal to the number of gallons of sewage per minute at the time of maximum flow, which, as is explained later, should be one and a half times the average per minute of the total daily flow.

Each district should be provided with ejectors of the requisite size in duplicate, one being sufficient to cope with the ordinary work and the other held in reserve. The two ejectors should be worked alternately, say, every week or fortnight, to ensure that they are both kept in working order.

Cast iron pipes required for air and sealed sewage mains need not be of the same thickness as those used for water works, as the pressure under which they work is comparatively light. The following thicknesses are recommended for these mains :—

Diameter	$2\frac{1}{2}''$	$3''$	$4''$	$5''$	$6''$	$7''$	$9''$	$10''$	$12''$	$14''$	$15''$
Thickness	$''$	$\frac{3}{8}''$	$\frac{3}{8}''$	$\frac{13}{32}''$	$\frac{7}{16}''$	$\frac{1}{2}''$	$\frac{9}{16}''$	$\frac{9}{16}''$	$\frac{5}{8}''$	$\frac{5}{8}''$	$\frac{11}{16}''$

The weights of pipes of these thicknesses, 9 feet long, exclusive of the socket, would be as follows :—

	cwts.	qrs.	lbs.
$2\frac{1}{2}''$ diameter	0	3	22
$3''$,, ...	1	0	10
$4''$,, ...	1	1	20
$5''$,, ...	1	3	24
$6''$,, ...	2	1	27
$7''$,, ...	3	1	1
$9''$,, ...	4	2	24
$10''$,, ...	5	0	16
$12''$,, ...	6	3	13
$14''$,, ...	8	0	25
$15''$,, ...	9	2	3

The air mains, after being laid and covered in, should stand a test of not less than $1\frac{1}{2}$ times the working pressure of air for two hours, with a loss not exceeding 20%.

They should be tested periodically, and when found to lose more than the above limit in *one* hour, steps should be taken to stop the excess leakage. To do this, each section should be tested separately, having previously examined all stop valves and arranged for the fixing of a pressure gauge to the main in each section.

After the section in which any excessive leakage has taken place has been located, the air should be blown off, and about 1 lb. of concentrated oil of peppermint, or other strong smelling volatile oil, should be introduced into the pipe by removing the stop valve cover at the end of the defective section nearest to the compressor station. On restoring the pressure, the air contained in the pipe will be heavily scented, and if the latter is not laid at a greater depth than 3 feet, the position of the leak can generally be detected by carefully walking over the site of the pipe.

An early hour on a still morning should be chosen for the test, and it is scarcely necessary to state that the person conducting it should *not* himself place the essence in the pipe.

If this means of detection fail, the pipe will have to be cut in the centre of the section and each half tested separately, and so on in the same manner until the leak is confined to a comparatively short length, the whole of which can then be exposed. The leak will generally be found to be due to a cracked pipe, to a blown joint, or to a section of piping having settled in soft ground, Leakage in exposed joints which are only slightly defective can be ascertained by washing them over with soap and water, when the escaping air will blow small bubbles round the leak.

The following is a simple and practical rule for calculating the sizes of air and sealed sewage mains :—

It will be correct for all practical purposes to lay the sewage delivery pipes, so as to carry sewage at a velocity of $2\frac{1}{2}$ feet per second, and the air mains to carry compressed air at a velocity of 20 feet per second.

Divide the capacity of the ejector in gallons by twice the above velocities (in feet per second), and take the square root of the quotients. The results will give the diameter of the respective pipes in inches.

D=Diameter in inches.
G=Capacity of the ejector in gallons.
V=Velocity in feet per second.

$$\left.\begin{array}{l}\text{D=Diameter in inches.}\\ \text{G=Capacity of the ejector in gallons.}\\ \text{V=Velocity in feet per second.}\end{array}\right\} D=\sqrt{\frac{G}{2V}}$$

The following example will illustrate the above rule :—

What should be the size of the ejectors, the air main, and the sealed sewage main for a district having a population or 12,000, 6 cubic feet per head per diem being taken as the average water-supply ?

Population of district=12,000.

Average water-supply per day=12,000 × 6 cubic feet (37 : 5 gallons)=450,000 gallons.

Gallons of sewage per minute= $\frac{450,000}{24 \times 60}$ =$312\frac{1}{2}$ gallons.

Quantity at time of maximum flow=$312\frac{1}{2} \times \frac{3}{2}$ =469 gallons.

An ejector of 500 gallons capacity would therefore be required, and as one ejector should always be a stand-by, two ejectors of 500 gallons each should be provided. As regards the sizes of the mains, the diameter of the air mains would be equal to $\sqrt{\frac{500}{2 \times 20}}$ =4 inches (an even figure), and that of the sealed sewage main would be equal to $\sqrt{\frac{500}{2 \times 2\cdot5}}$ =10 inches.

The air pressure required to operate any particular ejector is calculated as follows :—

Suppose the level of the bottom of the ejector is 60 feet above any datum, and that of the end of the sealed sewage main, where the sewage is finally discharged, 90 feet above the same datum, the height through which the sewage is lifted would be 90-60=30 feet.

Suppose the sealed sewage main to be 10,000 feet in length from the ejector to the outfall, the diameter 12 inches, and the velocity $2\frac{1}{2}$ feet per second, the discharge would equal about 107 cubic feet per minute and (calculating from Taylor's Pipe Discharge Diagrams) the frictional resistance would amount to 2·8 feet per thousand, or a total of 28 feet for the whole length. Therefore, the total head to be overcome is equal to 30 feet the actual height and 28·0 feet the head due to friction, or 58·0 feet in all.

It requires an air pressure of 1 lb. per square inch to overcome a head of 2·3 feet of water, and therefore the pressure in the ejector to overcome the above resistance and drive out the sewage must be $\frac{58\cdot0}{2\cdot3}$ or 25·21 lbs. per square inch.

The diagram A is taken from a paper read by the late Mr. Edwin Ault before the Society of Engineers, and shows—

(*a*) the quantity of free air required per gallon of sewage for different lifts;

(*b*) the indicated horse power required per gallon of sewage for different lifts; and

(*c*) the percentage of usual effects obtained with Shone's Pneumatic Ejectors.

From a purely sanitary point of view, this system is *theoretically* perfect, for the sewage is rapidly removed in a fresh state from the inhabited portions of the town to the ejectors, but this undeniable advantage is accompanied by certain drawbacks: it is expensive both as regards efficiency and initial cost, the apparatus required including the air compressing machinery, the cast iron air mains and sealed sewage mains, and its ejectors and ejector chambers; these, however, are not luxuries but necessities where a gravitation system cannot be adopted and sanitary conditions are desired. The defects of the system and loss of efficiency are due to—

(1) the impossibility of using the air expansively as in steam;

(2) the heating of the air during compression;

(3) subsequent loss of pressure on cooling;

(4) the leakage of air mains;

(5) leakage of the valves at the ejectors; and in inspection chambers, and

(6) the difference in head at the different ejector stations.

The efficiency obtained varies with the head to which the sewage has to be lifted, as shown by the diagram referred to above.

In designing new ejector stations, it is desirable, after all calculations for levels have been fixed, to lower the Station, together

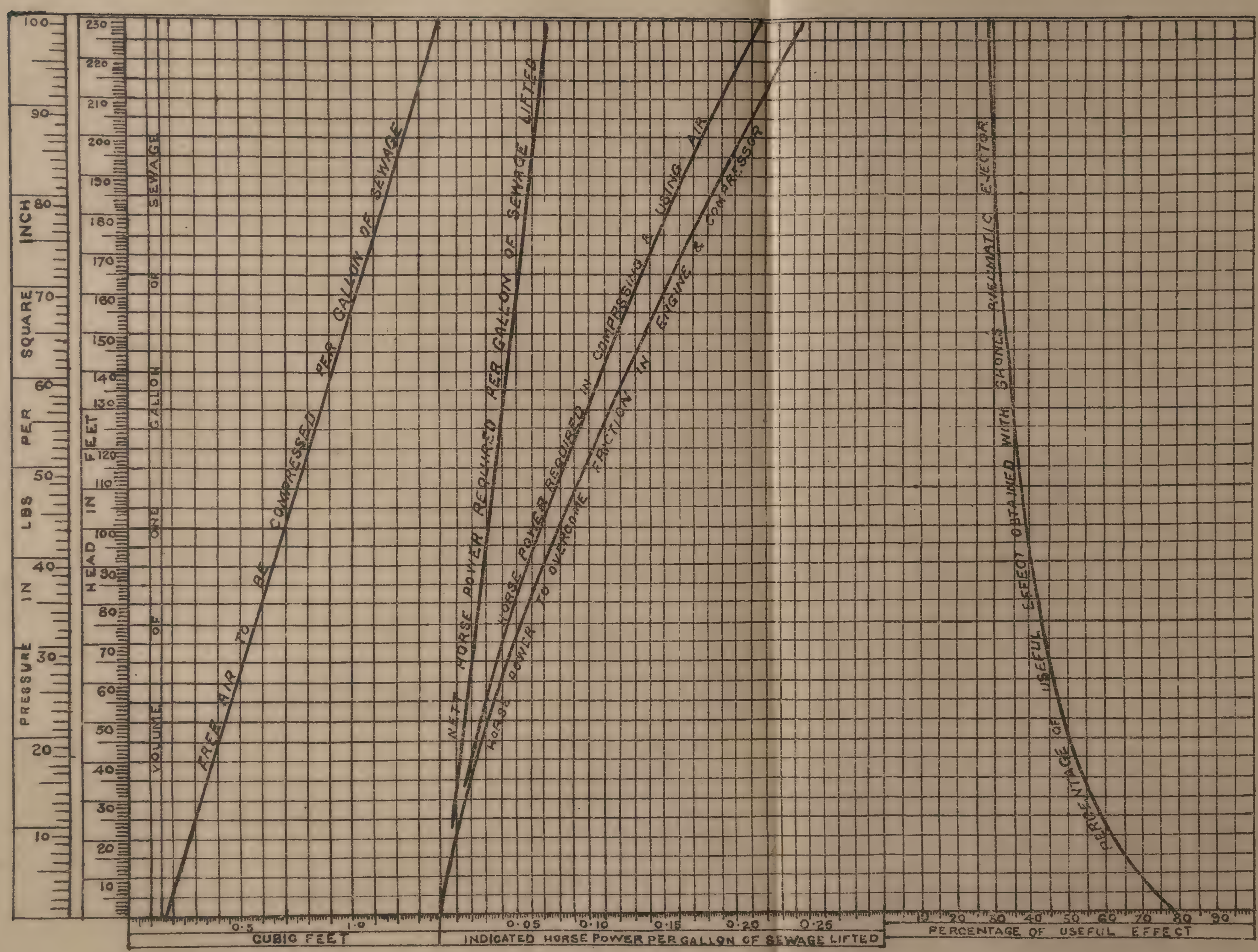
with the inlet manhole, by an amount equal to the size of the particular ejector.

Hydraulic System.—As an example of the use of hydraulic power for lifting sewage from low-lying areas, which cannot be drained to a general outfall by simple gravitation, may be mentioned the Installation at Working, in Surrey, which was completed in the year 1900. As in the Pneumatic System, the power is generated at a central station and transmitted through pipes to the various automatic pumping stations which, in the town under reference, are four in number. Several reasons induced the engineers, Messrs. John Taylor and Sons, to adopt water power in preference to air in this district. The principal reason was the desirability of placing the central station on the sewage farm where the whole of the sewage was purified. The power water being obtained from the subsoil water on the farm, an excellent means of assisting to keep the subsoil water at as low a level as possible was thereby provided. A well was sunk on the farm near the engine house, from which all the water necessary for working the pumps was obtained. The natural level of the water in the well was, on the average, some 6 feet below ground level, and is now, no doubt, being maintained in level by the sewage placed upon the sewage farm. As, however, the effluent coming from the farm is an extremely good one, the water in the well maintains a fair degree of purity.

Another reason for adopting hydraulic power was that the arrangement provided a means of storing the water in overhead cast iron tanks after it had done its work of pumping the sewage, and subsequently employing it for street watering or sewer flushing.

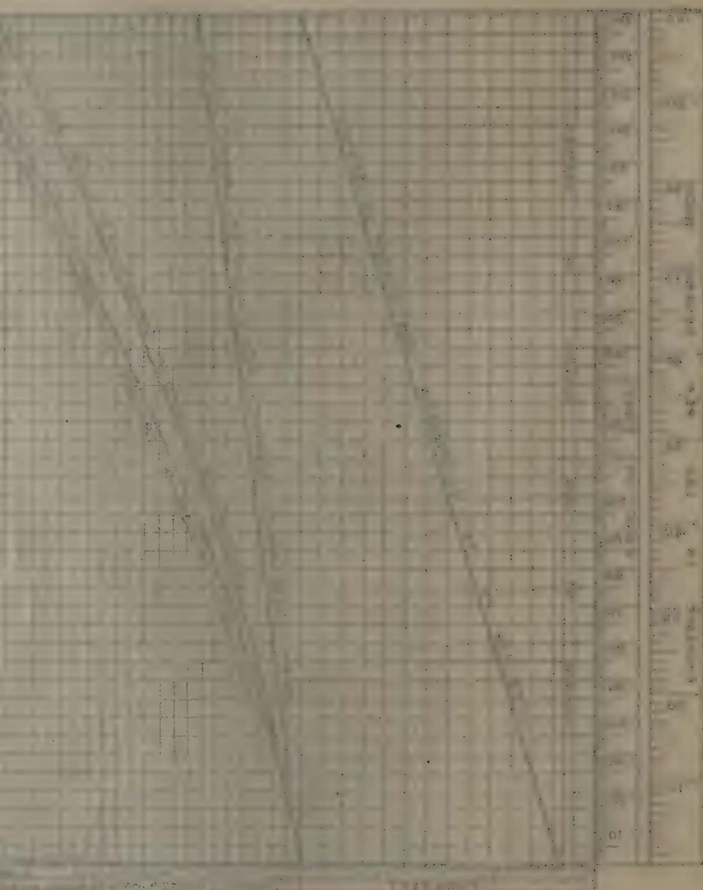
The hydraulic pressure employed is 200 lbs. to the square inch : this is rather a low pressure to adopt for power transmission, but as has already been explained, there is in this case plenty of water, and in fact the more used the better. The adoption of a low pressure enabled the pipes required for conveying the power from the generating station to the automatic pumps to be of a lighter and

DIAGRAM A.



PRESSURE IN LBS PER SQUARE INCH
HEAD IN FEET
VOLUME OF ONE GALLON OF SEWAGE
FREE AIR TO BE COMPRESSED PER GALLON OF SEWAGE
NETT HORSE POWER REQUIRED PER GALLON OF SEWAGE LIFTED
HORSE POWER REQUIRED IN COMPRESSING & USING AIR
HORSE POWER TO OVERCOME FRICTION IN ENGINE & COMPRESSOR
PERCENTAGE OF USEFUL EFFECT OBTAINED WITH SHONE'S PNEUMATIC EJECTOR
CUBIC FEET
INDICATED HORSE POWER PER GALLON OF SEWAGE LIFTED
PERCENTAGE OF USEFUL EFFECT

DIAGRAM [illegible]



less expensive make than they would have been had the pressure been 1,000 or 1,200 lbs. to the square inch, and reduced the cost of laying and jointing.

AUTOMATIC HYDRAULIC PUMPING STATION.

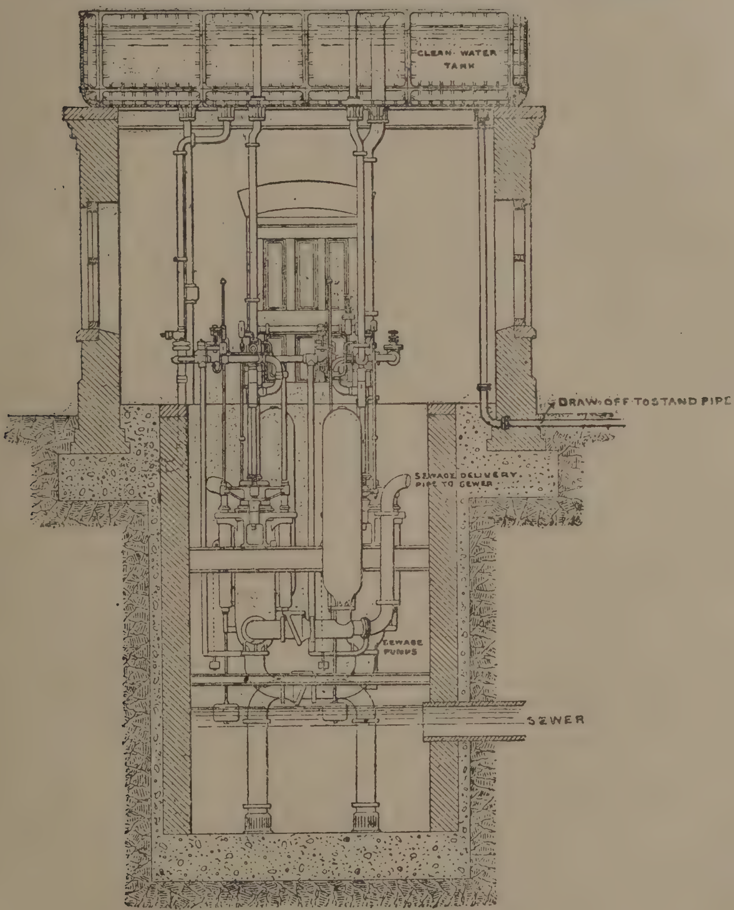


FIG. 2

An additional and very important advantage in the adoption of the low pressure is that the size of the accumulator ram can be increased, thus preventing sudden and rapid oscillations when the outlying sewage pumps are automatically opened or closed.

The pipes are of the ordinary spigot and socket type, and the joints were made by first forcing a strip of cold lead into the bottom of the socket and subsequently running the joint with lead and setting up in the usual manner.

The power generating plant at the sewage farm consists of a pair of horizontal compound steam engines, each driving hydraulic pumps direct in line behind the cylinders. These engines work at a steam pressure of 140 lbs. per square inch, and make 90 revolutions per minute. The diameters of the high and low pressure cylinders are 6 inches and 10 inches, respectively, both having a stroke of 12 inches. The pumps, which have 4½-inch pistons and 3-inch rams, discharge direct to an accumulator, and from thence the water is forced through the hydraulic main to the automatic pumps at the various outstations. The accumulator ram is 11 inches diameter with a stroke of 10 feet. The rise and fall of the accumulator by means of an equilibrium valve on the main steam pipe, which is connected to a weight suspended directly over the accumulator, automatically admits steam to, or cuts it off from, the engines. It is thus only necessary to keep up the pressure of steam in the boilers for the whole system to be in actual automatic working order. The machinery at the various automatic lifting stations, which is shewn in detail in Fig. 2, is in duplicate, and is controlled by means of counter-balanced floats which start or stop the pumps according to the level of the sewage in the sumps. The pumps are single acting, the plungers being forced downwards by means of a fixed operating ram, within which slides an operating cylinder. A slide valve worked by hydraulic pressure is alternately placed in communication with the pressure water and with the exhaust. The upward stroke is accomplished by means of two side rams constantly open to the pressure. The plungers of these pumps vary in size at the various stations according to the quantity of sewage to be disposed of, the largest being 2 feet in diameter with a three-foot stroke, the smallest being 1 foot diameter with the same length of stroke. The average lift is 16 feet. The installation,

with the exception of the pressure and rising mains, was laid down by the Hydraulic Engineering Company, Chester, and so far the results have borne out the most sanguine hopes of the Engineers.

Margate is another instance where sewage is lifted by hydraulic power, the automatic pumps used being those known as the Latham Davey Hydraulic Pumps. In this case special allowance had to be made for the fluctuating population which, though normally amounting to 20,000, increases to more than three times that number in summer.

The drainage is on the "separate" system, pumping being only used when gravitation fails. The sewage, after being raised by the hydraulic pumps, is discharged into a high level sewer. The high pressure water for these pumps is obtained by means of a pair of Worthington direct-acting high pressure engines. The full hydraulic pressure is 700 lbs. per square inch. The accumulator cylinder contains a 4-inch ram weighted to 6 tons. There are three pumping stations at different points, the lifts being 19, 28, and 38 feet, respectively. Each pump can work twelve strokes per minute, delivering 40 gallons per stroke.

Electrical System.—The adoption of electricity as a motive power for lifting sewage is of comparatively recent date.

In towns, which have electric tramways and electric light and possess any surplus power, it might be both desirable and economical to make use of this power for lifting sewage, if such lifting be necessary.

Electricity can, as is well known, be transmitted great distances at little cost beyond the initial outlay upon the cables, so that in other places where sufficient water power can be obtained all the year round at a convenient distance from the point where the sewage is to be lifted, it may be economical to instal turbines and electric generators at the source of power and electric motors coupled to pumps at the pumping station.

One of the earliest electric sewage pumping installations was laid down at Coombs, near Stowmarket in Suffolk, England, by Messrs. John Taylor and Sons.

The drainage of Coombs, which is only a small village, was undertaken, in conjunction with that of Stowmarket and Stow Upland, the sewage from both places being disposed of on a sewage farm. This farm being on a higher level than the village of Coombs, it became necessary to provide a small pumping installation for lifting purposes, which would entail the minimum amount of annual expenditure for upkeep and attendance.

An electric installation having been provided at Stowmarket for the lighting of that town, it was decided that no better arrangement could be adopted than to utilise the surplus power there generated. The following is a brief description of the arrangement of pumps and motors :—

> The machinery is in duplicate, each set comprising a 3-throw pump driven by an electric motor through worm gearing running on ball bearings. The bearings of the motor are lubricated automatically, the worm and wheel running in an oil bath, so that no attention should be required other than to start the motors and stop them, when necessary. But even this labour has been dispensed with by the use of automatic switches, operated by floats controlled by the level of the sewage in the sump adjoining the pumping station. These switches can be adjusted so as to start either pump in advance of the other, and a convenient arrangement is to allow one pump to deal with the ordinary flow of sewage, the second pump remaining in reserve and only starting in the event of the first being unable to cope with any increased flow of sewage. As either pump can be made to start first, they can be worked alternately week by week, or month by month, as desired, so that both sets of machinery are kept in good working order and do an

equal amount of work. In a pumping installation, which derives its power from an electric light plant, the current must be so drawn off as to cause no great fluctuation likely to appreciably affect the electric lights burning on the circuit; and for this purpose on the Coombs installation an arrangement consisting of a dash-pot with a multiple contact automatic switch has been used, by which the starting-current is gradually turned on, the movement occupying a period of from 5 to 10 seconds.

The absence of steam, gas, or oil engines in a pumping installation of this description enables the station to be kept scrupulously clean. The plant has now been working for nearly two years and has given considerable satisfaction.

The same firm has, at Shrewsbury, erected in St. Mary's Water Tower an automatic electrically driven pumping machinery. The electric motors are 7 H.P. and are coupled direct to two sets of 3-throw pumps with $6\frac{1}{4}$-inch diameter plungers and 9-inch stroke. They are driven from the Corporation current through electric motors and worm gearing. After a careful test, extending over several weeks, it was ascertained that with 2,654,200 gallons of water lifted to an average height of 75 feet, by 1,803 units of electricity, the efficiency was 41·82 per cent. This probably represents a fair efficiency for electric pumping. With a smaller lift it is probable that the efficiency would be slightly higher. It may be confidently asserted that the efficiency of an electrically driven pump will vary between 40 and 50 per cent.

At Cardiff also, an electrical plant for pumping the sewage has been erected by the City Engineer, the power being drawn, as at Coombs, from an Electric Light Installation.

The motors and pumps are placed in a small chamber beneath the roadway, and the motors are directly connected with 3-inch centrifugal pumps with vertical spindles: special bearings are fitted to the motors, so that the spindles run in a bath of oil and the thrust is taken by adjustable ball bearings.

The speed of the motors is about 1,300 revolutions per minute and they are series wound and work on a 500-volt circuit.

The installation has given great satisfaction, and is economical and clean in working.

In Bedford, a town of considerable population, the Corporation some years ago made use of their surplus electric power to pump a portion of their sewage. 25 H.P. electric motors in duplicate were provided for driving a 7 inch centrifugal pump, also in duplicate. The electricity is generated at works situated about a mile from the sewage pumping station. The cost per unit was reduced until it arrived at three half-pence. But even at this rate the cost was calculated to exceed by £400 per annum the cost of a steam-driven system. Moreover, no economy in staff was possible, the same number of men being required as when steam was used.

In selecting for a particular town any one of the systems described in this chapter, it must be remembered that financial considerations, though very important in a sewerage scheme, should take only a second place, the first desideratum being the efficient removal of the sewage. Of the various systems above described the simplest and the least expensive is undoubtedly the " gravitation " system. Here the sewage flows to the outfall through conduits laid at gradients, which should be self-cleansing. This is the ideal system which every Sanitary Engineer desires to obtain, but unfortunately in most towns of any size it is impossible and some kind of pumping has to be resorted to.

It is not necessary in all cases to have recourse to sectional pumping. In many schemes the sewage of a town can be gravitated to a single point and there lifted in one lift. This is often the most economical system next to that of simple gravitation. Cases occur where the town as a whole is situated at a high level, and can be drained by gravitation, but a small district is at a low level, and its sewage has to be lifted to discharge through a gravitation sewer.

In these conditions an automatic sewage lift can be employed by which the sewage of one of the high level sewers is intercepted, and by its descent generates the power to lift the low level sewage.

Adams "Autaram" or sewage lift utilizes the fall of sewage by means of a series of automatic syphons and cylinders, and raises a similar volume of sewage from a low level sewer to a sewer at the intermediate level.

The lifts are entirely automatic, and beyond an occasional inspection, require no attention. They are noiseless and give off no offensive gases, but they are only suitable for places where a small portion of the sewage has to be lifted, and when it is possible to place the air and forcing chambers within a moderate distance of each other.

This system has been adopted with satisfactory results at several places in the United Kingdom, notably at Douglas, Isle of Man, Devonport, Poole, Belfast, Axminster, etc.

In dealing with the various systems of sectional pumping, it is very difficult to say that either one or the other stands first in any marked degree. Circumstances vary so much in many places, and where in one position the Pneumatic System of drainage may be the most economical, a hydraulic system may be the most expensive, and *vice versa*. Generally speaking, there is no doubt that the first cost of the Pneumatic System, as well as the expense of working it, is less than that of any hydraulic system. Lighter and smaller pipes and much less pressure are needed to work this system. The cost of water is greater than that of air, and although the water used in the hydraulic system is also used to flush the sewers, it takes up space in them, and allowance must be made for it. The Author has had considerable experience of the Pneumatic System of Drainage and, excepting the few disadvantages mentioned earlier, it has always given satisfaction.

CHAPTER II

Preliminary Data for a Sewage Scheme

A DRAINAGE system and its sewage outfall having been decided on it is necessary, in order that the capacity of the sewers may be determined, to ascertain its population, and water supply.

Population.—The main sewers of a town should be designed to make allowance for the increase of the town in the future, and it therefore becomes necessary to forecast the future population for some years in advance, that is to provide for the number of inhabitants, which can reasonably be expected to exist in it about 30 years hence, which is the rule of the Local Government Board of England, and is generally adopted, unless in very exceptional cases.

When a census is available, its figures should be taken unless there are reasons for doubting its accuracy. In many cities and undeveloped countries the census, if any, for various causes is not to be depended on, and an independent estimate must be made.

If the number of dwelling houses in a town is accurately known together with the average number of persons residing in a house, a fair approximation to the population can be arrived at; and again if the areas are known and these are multiplied by the number of persons per unit of area, the population will be ascertained with a correctness varying with the degree of accuracy with which the relative number of persons per house and per unit of area have been estimated. The Engineer in solving this problem has to exercise his judgment, based on his own experience and knowledge of the local conditions which would govern the growth of the town he has to deal with. The following table shows the number of persons in a dwelling house, and the density of population per acre in several cities and towns in various countries.

TABLE SHOWING NUMBER OF PERSONS IN A HOUSE IN VARIOUS CITIES AND TOWNS.

	Name of City or Town.	Persons in a dwelling.
	EUROPE.	
	England, average number	5
	London, Blocks of Flats varying in size ..	80 to 120
	AMERICA.	
North America (Canada)	Montreal City	6·3
	Toronto whole City	5·2
	,, densest portion	7·2
	Ottawa City	7·0
	Quebec ,, ...	6·5
	Average of whole Canada..	5·1
North America (U. S. A.)	New York City average	16·0
	,, ,, Flats	100·0
	Boston Flats	42·0
	New Orleans	6·0
	Providence	7·4
	Sacremento, California	5·0
South America	Para..	6·7
	Pernambuco	6·0
	Monte Video	5·6
	ASIA.	
Average of all India	.. ..	5·0
Calcutta City	.. ..	9·6
Bombay ,,	.. ..	14·4
Madras ,,	.. ..	7·5
Hyderabad	.. ..	4·4
Rangoon ..	.. ..	5·4
Cawnpore ..	.. ..	5 5
	AFRICA.	
Egypt ..	Cairo, whole City to Police boundary including Helwan and Giza	4·6
	Densest portion	6·3
	Alexandria whole City to Municipal boundary including Ramleh	8·4
	Densest portion	10·5
	Port Said	4·1
	Damanhur	7·3
	Ismalia	4·0
	Suez	3·8
	Rosetta	8·0
	Damietta	7·0
	Mansura	4·5
	Tanta	5·2
	Zagazig	6·1

	Name of City or Town.	Persons in a dwelling.
Upper Egypt	Assiut	6·0
	Beni Suef	5·2
	Fayum	9·4
	Akhmim	5·3
	Minia	5·2
	Average of 45 towns	5·6

TABLE SHOWING POPULATION PER ACRE FOR VARIOUS CITIES AND TOWNS.

	Name of City or Town.	Population per acre.
	EUROPE.	
London ..	City portion and London County Council workmen's flats	409
	Working class districts	200
	Suburban districts mixed houses	127
	,, detached houses with gardens ..	35
Birmingham ..	Dense City portion	125 to 147
	Large Suburban houses	17
Aberdeen ..	Before extension of boundaries	50
	After ,, ,, ...	25
Constantinople St	amboul	200
	NORTH AMERICA.	
Canada ..	Montreal City	98
	Totonto whole City	35
	,, densest portion	82
	Ottawa	30
	Quebec City	40
	,, densest portion	110
	Ordinary towns laid out in squares do not as a rule average more than	50
	SOUTH AMERICA.	
Para ..	Dense City portion	70
	Suburban districts.	20
Pernambuco ..	Dense City portion	90
	Suburban districts	20
Buenos Aires ..	.. ..	75

	Name of City or Town.	Population per acre.
	ASIA.	
India	Calcutta including Fort William and Mardam	41
	,, dense central portions	200 to 281
	Bombay whole City	51
	,, dense central portions	555 to 600
	Madras whole City	35
	,, dense City portions	130 to 183
	Ahmedabad	170
	Rangoon	198
	Benares	125
	Lucknow Municipality	43
	Karachi	150
	Howrah	28
	Madurah	28
	Patna	27
	Poona	44
	Surat	63
	Srinigar	23
Shanghai	European Quarter	82
	Native City	170
	AUSTRALIA.	
Sydney	(New South Wales) closely built portion	47
	Whole districts	33
	AFRICA.	
Cairo	City	25
	Dense central portion	100
Alexandria	City	68
	Business portion	100
	Flats	130 to 307
	Suburban districts	28 to 50
Port Said built over portion		93

Rate of Future Increase.—Having estimated the present population and the rate of increase in the past, it is usual to assume that the town will continue to grow regularly in accordance with the same law.

In eastern countries, visitations of plague, cholera, and famine have a material effect on the natural growth of a city. For instance Bombay, which had a population of 821,764, in 1891, had only 776,000 in 1901, a decline mainly caused by intermediate plague years.

To forecast the future population the best method is by a diagram, on which all the known populations of past years are plotted, a curve drawn through them, and with the same law of curvature continued to the end of the period for which the works are to be designed. It will be necessary however to modify the curve in accordance with the well-ascertained fact that the rate of increase for towns of different populations tends to decrease as the size of the town increases.

Flow of Sewage.—Population affects sewage works, inasmuch as each individual member of the community uses a certain amount of water, and contributes a certain amount of solid matter to the sewers.

The quantity of water supplied daily to any area is generally discovered without difficulty, but in India it varies considerably between the Mofussil town, with its well supply of from 5 to 7 gallons per head, and a city like Bombay, with its lakes and pipes capable of supplying 40 gallons per head per day.

In the latter class of cases, the Engineer should allow from 35 to 40 gallons per head per day, but owing to the fact that in Eastern as well as in other countries, the largest amount of water is used in the early morning, one half of the average daily supply should be assumed to flow off within 8 hours, so that the sewer capacity should be made capable of conveying this maximum amount.

For instance if the population of a town is 10,000, and the water supply 20 gallons per head per day, the flow of sewage during the 24 hours will be 200,000 gallons to the sewage outfall. But to take the maximum flow, the sewer capacity must be made capable of carrying 100,000 gallons in 8 hours, or 208 gallons per minute.

The minimum velocity of sewage, usually held to be sufficient for satisfactory self-cleansing in England, may be taken at 2·5 feet per second; but a greater velocity than this is usually allowed for, especially on small sewers up to 12 inches in diameter. A velocity of 2·5 feet per second has been found to be insufficient

for India, and after considerable experience, the Author is of opinion that in Eastern countries a minimum velocity of 3·5 feet per second should be taken for all sewers, on account of the heaviness of some of the foreign matter in the sewage. It is essential that every sewer should be of such dimensions, and laid at such a gradient, that the volume of sewage delivered to it will always be of a depth within it sufficient to maintain the given velocity.

The formula used and published in tables and diagrams for use in designing sewers and water mains by Messrs. W. Santo Crimp and C. Ernest Bruges has been found to be reliable. It was devised by Messrs. Crimp and Bruges after experiments carried out on the London sewers. The results of the formula closely follow the results obtained from the well-known Kutter formula, which is, however, cumbersome and labourious to work out. By adjusting the co-efficient given in the formula, *viz.*, 124, the results obtained may be made to correspond with Kutter's formula for different co-efficients of roughness. The co-efficient 124 corresponds with Kutter's N = ·012. The formula may be confidently used in the design of drainage works, in which stoneware pipes and brickwork of good quality are to be employed.

It is as follows :— $v = 124 \sqrt[3]{r^2} \quad \sqrt{s}$

Where v = Velocity in feet per second.
r = Hydraulic mean depth in feet.
s = Fall divided by the length.

For circular pipes running full or half full, this is equivalent to

$$V = \frac{563 \sqrt{D}}{\sqrt{I}}, \qquad Q = \frac{3{\cdot}072 \quad \sqrt[3]{D^8}}{\sqrt{I}}$$

Where V = Velocity in feet per minute.
D = Diameter in inches = 48 r.
I = Inclination or the length divided by the fall $= \frac{1}{8}$
Q = Cubic feet per minute delivered when running full.

The following example illustrates the working of the formula :—

Find, for example, the velocity and discharge of a 9-inch pipe sewer at a gradient of 1 in 200.

$$r = \frac{.75}{4} = \cdot 19 \text{ nearly.}$$

$$\therefore \sqrt[3]{r^2} = \cdot 3305.$$

$$\& \ v = 124 \times \cdot 3305 \times \sqrt{\frac{1}{200}} = \frac{40 \cdot 94}{14.14} = 2.89 \text{ feet per second ; or thus}$$

$$V = \frac{563 \sqrt[3]{81}}{\sqrt{200}} = 172 \text{ feet per minute.}$$

and $Q = 4418 \times 172 = 76$ cub. feet per minute.

This result, as will be seen from the forgoing remarks, shews that the gradient is not sufficiently steep for a 9-inch pipe sewer.

In the same way, with the above formulæ, the velocity and the discharge of any sewer can be calculated.

As already stated there is a limit to the maximum velocity of flow in sewers, because of the solid matter in the sewage which tends to wear away the inside surface of the sewers. Several authorities, including Rankine and Rawlinson, limit this velocity to 4·5 feet per second, which, in the opinion of the Author, is a low limit; but in deciding such a question, the quality of the sewage to be dealt with must be considered. In Bombay, the sewage contains a large quantity of road detritus, derived from the basaltic rock with which all the roads are macadamised. In such sewage, a maximum velocity of 5 feet per second should be given, but in ordinary domestic sewage 6 feet per second may be allowed without danger.

The modern practice in sewage schemes is to use pipes and sewers of relatively much smaller diameters than those used in former years, and this more especially refers to pipe sewers. It has often been found with pipes laid years ago that they have

never ordinarily carried more than 1-5th of their full capacity and it is manifestly more economical in such cases to use pipes of a smaller diameter. Other considerations, however, impose a limit on a minimum size, and it is not advisable to lay any pipe sewer of a less diameter than 7 inches, even though calculations based on the formula already quoted might shew that a pipe of much smaller capacity would do all the work required. The practice in Bombay in past years has been to lay pipe sewers of 9 inches in diameter as a minimum, but this is somewhat large.

Small sewers require a greater inclination than larger ones, and pipe sewers require less inclination than brick sewers.

For ready reference, certain tables are here inserted, calculated from the formulæ already given.

Table I gives the value of $\sqrt[3]{r^2}$ for different values of "r" from ·01 to ·3.

TABLE I.

GIVING THE VALUE OF $\sqrt[3]{r^2}$

r.	$\sqrt[3]{r^2}$	r.	$\sqrt[3]{r^2}$	r.	$\sqrt[3]{r^2}$	r.	$\sqrt[3]{r^2}$	r.	$\sqrt[3]{r^2}$	r.	$\sqrt[3]{r^2}$	r.	$\sqrt[3]{r^2}$	r.	$\sqrt[3]{r^2}$	r.	$\sqrt[3]{r^2}$	r.	$\sqrt[3]{r^2}$
		·30	·4481	·60	·7114	·90	·9322	1·20	1·129	1·50	1·310	1·80	1·480	2·10	1·640	2·40	1·793	2·70	1·939
·01	·0464	·31	·4580	·61	·7193	·91	·9391	1·21	1·136	1·51	1·316	1·81	1·485	2·11	1·645	2·41	1·798	2·71	1·944
·02	·0737	·32	·4678	·62	·7271	·92	·9459	1·22	1·142	1·52	1·322	1·82	1·491	2·12	1·650	2·42	1·803	2·72	1·949
·03	·0965	·33	·4775	·63	·7349	·93	·9528	1·23	1·148	1·53	1·328	1·83	1·496	2·13	1·656	2·43	1·808	2·73	1·953
·04	·1170	·34	·4871	·64	·7427	·94	·9596	1·24	1·154	1·54	1·334	1·84	1·502	2·14	1·661	2·44	1·813	2·74	1·958
·05	·1357	·35	·4966	·65	·7504	·95	·9664	1·25	1·160	1·55	1·339	1·85	1·507	2·15	1·666	2·45	1·818	2·75	1·963
·06	·1533	·36	·5061	·66	·7531	·96	·9732	1·26	1·167	1·56	1·345	1·86	1·513	2·16	1·671	2·46	1·822	2·76	1·968
·07	·1699	·37	·5154	·67	·7657	·97	·9799	1·27	1·173	1·57	1·351	1·87	1·518	2·17	1·676	2·47	1·827	2·77	1·973
·08	·1857	·38	·5246	·68	·7733	·98	·9866	1·28	1·179	1·58	1·357	1·88	1·523	2·18	1·681	2·48	1·832	2·78	1·977
·09	·2008	·39	·5338	·69	·7809	·99	·9933	1·29	1·185	1·59	1·362	1·89	1·529	2·19	1·686	2·49	1·837	2·79	1·982
·10	·2154	·40	·5429	·70	·7884	1·00	1·000	1·30	1·191	1·60	1·368	1·90	1·534	2·20	1·692	2·50	1·842	2·80	1·987
·11	·2296	·41	·5519	·71	·7959	1·01	1·007	1·31	1·197	1·61	1·374	1·91	1·540	2·21	1·697	2·51	1·847	2·81	1·991
·12	·2433	·42	·5608	·72	·8033	1·02	1·013	1·32	1·203	1·62	1·379	1·92	1·545	2·22	1·702	2·52	1·852	2·82	1·996
·13	·2566	·43	·5697	·73	·8107	1·03	1·020	1·33	1·210	1·63	1·385	1·93	1·550	2·23	1·707	2·53	1·857	2·83	2·001
·14	·2696	·44	5785	·74	·8181	1·04	1·026	1·34	1·216	1·64	1·391	1·94	1·556	2·24	1·712	2·54	1·862	2·84	2·005
·15	·2823	·45	·5872	·75	·8255	1·05	1·033	1·35	1·222	1·65	1·396	1·95	1·561	2·25	1·717	2·55	1·867	2·85	2·010
·16	·2947	·46	·5959	·76	·8328	1·06	1·040	1·36	1.228	1·66	1·402	1·96	1·566	2·26	1·722	2·56	1·871	2·86	2·015
·17	·3069	·47	·6045	·77	·8401	1·07	1·046	1·37	1.234	1·67	1·408	1·97	1·572	2·27	1·727	2·57	1·876	2·87	2·019
·18	·3188	·48	·6130	·78	·8474	1·08	1·053	1·38	1.240	1·68	1·413	1·98	1·577	2·28	1·732	2·58	1·881	2·88	2·624
·19	·3305	·49	·6215	·79	·8546	1·09	1·059	1·39	1.246	1·69	1·419	1·99	1·582	2·29	1·737	2·59	1·886	2·89	2·029
·20	·3420	·50	·6300	·80	·8618	1·10	1·066	1·40	1.252	1·70	1·424	2·00	1·587	2·30	1·742	2·60	1·891	2·90	2·034
·21	·3533	·51	·6384	·81	·8690	1·11	1·072	1·41	1.257	1·71	1·430	2·01	1·593	2·31	1·748	2·61	1·896	2·91	2·038
22	·3644	·52	·6467	·82	·8761	1·12	1·078	1·42	1·263	1·72	1·436	2·02	1·598	2·32	1·753	2·62	1·901	2·92	2·043
·23	·3754	·53	·6550	·83	·8832	1·13	1·085	1·43	1·269	1·73	1·441	2·03	1·603	2·33	1·758	2·63	1·905	2·93	2·048
·24	·3862	·54	·6632	·84	·8903	1·14	1·091	1·44	1·275	1·74	1·447	2·04	1·609	2·34	1·763	2·64	1·910	2·94	2·052
·25	·3969	·55	·6714	·85	·8973	1·15	1·098	1·45	1·281	1·75	1·452	2·05	1·614	2·35	1·768	2·65	1·915	2·95	2·057
26	·4074	·56	·6795	·86	·9043	1·16	1·104	1·46	1·287	1·76	1·458	2·06	1·619	2·36	1·773	2·66	1·920	2·96	2·062
·27	·4178	·57	·6875	·87	·9113	1·17	1·110	1·47	1·293	1·77	1·463	2·07	1·624	2·37	1·778	2·67	1·925	2·97	2·066
·28	·4280	·58	·6955	·88	·9183	1·18	1·117	1·48	1·299	1·78	1·469	2·08	1·630	2·38	1·783	2·68	1·929	2·98	2·071
·29	·4381	·59	·7035	·89	·9253	1·19	1·123	1·49	1·305	1·79	1·474	2·09	1·635	2·39	1·788	2·69	1·934	2·99	2·076
·30	·4481	·60	·7114	·90	·9322	1·20	1·129	1·50	1·310	1·80	1·480	2·10	1·640	2·40	1·793	2·70	1·939	3·00	2·080

Table II gives the areas in square feet of circular sewers and pipes, mostly used in sewerage works, and the value of $\sqrt[3]{r^2}$ when running full.

Table III gives the areas of the principal egg-shaped sewers in square feet and the value of $\sqrt[3]{r^2}$ when running full, two-thirds full and one-third full.

Table IV gives the gradients at which different sizes of pipe sewers should be laid to give different velocities, when running full or half full.

Table V give the gradients at which different sizes of ovoid sewers should be laid to give different velocities when running full.

TABLE II.

AREAS OF CIRCULAR SEWERS AND PIPES IN SQUARE FEET AND THE VALUE OF $\sqrt[3]{r^2}$ WHEN RUNNING FULL.

(r = *Hydraulic mean depth in feet.*)

Diameter in inches.	Area in square feet (full).	$\sqrt[3]{r^2}$
4	·0873	·1908
6	·1963	·2500
7	·2672	·2771
8	·3491	·3029
9	·4418	·3276
10	·5454	·3514
12	·7854	·3969
15	1·2272	·4605
18	1·7671	·5200
21	2·4053	·5763
24	3·1416	·6300
27	3·9761	·6814
30	4·9087	·7310
33	5·9396	7790
36	7·0686	·8255

TABLE III.

AREAS OF EGG-SHAPED SEWERS (OLD FORM) IN SQUARE FEET AND THE VALUE OF $\sqrt[3]{r^2}$

(r=Hydraulic mean depth in feet.)

SIZE.					FULL.		TWO-THIRDS FULL.		ONE-THIRD FULL.	
Width.			Height.		Area in square feet.	$\sqrt[3]{r^2}$	Area in square feet.	$\sqrt[3]{r^2}$	Area in square feet.	$\sqrt[3]{r^2}$
Ft.	In.		Ft.	In.						
1	8	×	2	6	3·1903	·6154	2 0994	·6518	·7889	·4912
2	0	×	3	0	4·5940	·6950	3·0232	·7360	1·1360	·5548
2	4	×	3	6	6·2529	·7702	4·1149	·8156	1·5462	·6147
2	6	×	3	9	7·1781	8064	4·7237	·8540	1·7750	·6437
2	8	×	4	0	8·1671	·8419	5·3746	·8915	2·0195	·6720
3	0	×	4	6	10· 337	·9107	6·8022	·9644	2·5560	·7269
3	4	×	5	0	12· 761	·9770	8·3978	1·0346	3·1556	·7799
3	6	×	5	3	14· 069	1·0092	9·2585	1·0688	3·4790	·8056
3	10	×	5	9	16· 877	1·0734	11· 106	1·1356	4·1732	·8560
4	0	×	6	0	18· 376	1·1032	12· 093	1·1683	4·5440	·8806
4	6	×	6	9	23· 257	1·1933	15· 305	1·2637	5·7510	·9526
4	8	×	7	0	25· 012	1·2226	16· 460	1·2948	6·1849	·9759
5	4	×	8	0	32· 668	1 3365	21· 498	1·4152	8·0782	1·0668
6	0	×	9	0	41· 346	1·4457	27· 209	1·5309	10·0224	1·1540

TABLE IV.

RATES OF INCLINATION OF CIRCULAR SEWERS TO GIVE THE FOLLOWING VELOCITIES WHEN RUNNING FULL OR HALF-FULL.

Velocity in feet per second.	Diameter 4 in.	Diameter 6 in.	Diameter 7 in.	Diameter 8 in.	Diameter 9 in.	Diameter 10 in.	Diameter 12 in.	Diameter 15 in.	Diameter 18 in.	Diameter 21 in.	Diameter 24 in.	Diameter 27 in.	Diameter 30 in.
2	1 in 140	1 in 240	1 in 295	1 in 350	1 in 415	1 in 475	1 in 610	1 in 820	1 in 1050	1 in 1275	1 in 1525	1 in 1775	1 in 2050
2½	1 in 89	1 in 155	1 in 190	1 in 225	1 in 265	1 in 305	1 in 385	1 in 520	1 in 660	1 in 820	1 in 970	1 in 1133	1 in 1315
3	1 in 62	1 in 105	1 in 130	1 in 155	1 in 185	1 in 210	1 in 270	1 in 365	1 in 460	1 in 570	1 in 680	1 in 790	1 in 910
3½	1 in 46	1 in 78	1 in 96	1 in 115	1 in 135	1 in 155	1 in 200	1 in 265	1 in 340	1 in 415	1 in 500	1 in 585	1 in 670
4	1 in 35	1 in 60	1 in 73	1 in 88	1 in 105	1 in 120	1 in 150	1 in 205	1 in 260	1 in 320	1 in 380	1 in 445	1 in 515
4½	1 in 28	1 in 47	1 in 58	1 in 70	1 in 82	1 in 94	1 in 120	1 in 160	1 in 205	1 in 250	1 in 300	1 in 352	1 in 405
5	1 in 22	1 in 38	1 in 47	1 in 56	1 in 66	1 in 76	1 in 97	1 in 130	1 in 165	1 in 205	1 in 245	1 in 285	1 in 330
5½	1 in 19	1 in 32	1 in 39	1 in 47	1 in 55	1 in 63	1 in 80	1 in 105	1 in 138	1 in 170	1 in 200	1 in 234	1 in 270
6	1 in 16	1 in 27	1 in 33	1 in 39	1 in 46	1 in 53	1 in 67	1 in 91	1 in 115	1 in 140	1 in 170	1 in 197	1 in 230

TABLE V.

RATES OF INCLINATION OF OVOID SEWERS (OLD FORM) TO GIVE THE FOLLOWING VELOCITIES WHEN RUNNING FULL.

Velocity in feet per second.	2′—0″ × 3′—0″	2′—6″ × 3′—9″	2′—8″ × 4′—0″	3′—0″ × 4′—6″	3′—4″ × 5′—0″	3′—10″ × 5′—9″	4′—0″ × 6′—0″	4′—8″ × 7′—0″	5′—4″ × 8′—0″
2	1 in 1850	1 in 2500	1 in 2725	1 in 3200	1 in 3650	1 in 4400	1 in 4700	1 in 5800	1 in 6890
2½	1 in 1200	1 in 1600	1 in 1750	1 in 2050	1 in 2350	1 in 2825	1 in 3000	1 in 3700	1 in 4400
3	1 in 825	1 in 1100	1 in 1200	1 in 1400	1 in 1634	1 in 1950	1 in 2075	1 in 2550	1 in 3050
3½	1 in 600	1 in 815	1 in 900	1 in 1050	1 in 1200	1 in 1450	1 in 1525	1 in 1875	1 in 2250
4	1 in 460	1 in 625	1 in 685	1 in 800	1 in 900	1 in 1100	1 in 1175	1 in 1440	1 in 1700
4½	1 in 355	1 in 500	1 in 538	1 in 630	1 in 725	1 in 875	1 in 925	1 in 1130	1 in 1350
5	1 in 300	1 in 400	1 in 435	1 in 500	1 in 590	1 in 700	1 in 750	1 in 910	1 in 1100

Benefits to be derived from a Good System of Sanitation.

The conditions for preserving the health of the population of a great City are :—

First.—An efficient Quarantine to rigidly guard against the mportation of infectious diseases.

Secondly.—A well planned and efficient system of sewerage to remove sewage by water carriage from all houses. All privies, cesspits, etc., to be abolished.

Thirdly.—The provision of an adequate supply of pure water. These works to be supplemented by an improved construction of streets with impervious carriage ways and footways, and Bye-Laws to enforce the building of houses in conformity with modern sanitary conditions. The carrying out of such works is invariably followed by a great fall in the death rate, saving annually a great number of lives. Such works also promote the general comfort of the inhabitants, and attract a well fed and well clad population that would not reside in insanitary towns, where these favourable conditions do not exist.

The following are examples of the fall in the death rate of cities following the construction of sewerage works and water supply.

Buenos Aires, South America.—Before the sewerage works were carried out in 1891 the mortality was 32 per 1000. In 1894 t was, 14·9 or less than half.

Adelaide, South Australia.—Before construction of Sewerage works the mortality was 27·6 per 1000 ; after their completion it was 19·1 per 1000.

In Munich, the city drainage was completed in 1880, and in that year there were 492 cases of typhoid ; in 1881 there were 99, and in 1888 with a greatly increased population 94.

The average deaths from typhoid at Frankfort-on-the-Main up to 1870 were 89, and in some years 110 per 100,000 of the population on the introduction of a system of sewerage and water supply, the mortality fell to 40, and in 1887, when 85 per cent. of the

houses were supplied with water, and nearly 80 per cent. were connected with the sewers, it was a little over 5 per 100,000.

The typhoid death rate at Berlin before the sewerage system was installed in 1875 was 0·23 per cent. of the total deaths, whilst in 1890 it was only 0·04.

The following table, which gives the death rates in 13 cities and towns in Great Britain before and after the execution of modern sanitary works, shows the substantial improvement that results.

POPULATION AND DEATHS PER 1000 IN LONDON AND TWELVE OTHER LARGE TOWNS OF GREAT BRITAIN.

Cities and Towns.	Estimated population Before.	Deaths per 1000.	Estimated population after.	Deaths per 1000.	Saving of life per cent.
Average of 23 towns ..	8,502,896	26·4	15,271,287	17·2	35·
London	3,620,868	23·7	4,648,950	16·6	30·
Leicester	125,622	26·7	224,186	14·5	45·
Bristol	209,947	26·9	343,204	15·6	42·
Wolverhampton	75,100	22·1	98,194	15·5	37·
Bradford	191,046	27·2	285,089	17·6	35·
Nottingham	169,398	26·4	248,811	17·7	33·
Oldham	118,318	27·0	139,497	18·2	33·
Geasgow	578,156	28·6	798,357	19·2	33·
Leeds	311,862	26·5	450,140	18·0	32·
Sheffield	297,138	24·9	432,490	16·8	32·
Hull	146,347	27·5	253,865	18·6	32·
Edinburgh	226,075	23·7	331,977	16·6	30·
Manchester..	361,819	30·0	557,938	21·3	29·

CHAPTER III

Sewers and their Construction

The materials other than metals, such as iron and steel, used in the construction of sewerage works are cement, lime, sand mortar, concrete, bricks, stone, and pipes.

Cement.—The best known natural cement is Roman cement, which is made from a stone found in the form of nodules in the Island of Sheppey and elsewhere in the geological formation, known as "London Clay." This cement was first discovered by a Mr. Parker in the year 1796, and usually contains 55 parts of lime, 38 of clay, and 7 of iron. In Russia, America, India, and elsewhere, similar natural cements have been met with, but they are comparatively rare. This rarity necessitated the making of an artificial cement, and we are much indebted to General Paisley for one of our best and earliest artificial cements: it was he who first proved that an artificial cement equal to that obtained from natural source, could be prepared; and he composed it of a mixture of chalk and blue alluvial clay, the proportion being four parts by weight of chalk and 5·5 parts of clay.

The principal cement used in sanitary works is that known as Portland cement. Portland cement is so named simply because of its similarity in colour to Portland stone, but it has no connection with it in any other way. It is usually manufactured on the banks of the Thames and the Medway, from a mixture of chalk and mud obtained from the beds of those rivers. Other materials are also employed in its manufacture, such as blue lias limestone and shale. There are many makers and many brands of this class of cement, but in all a mixture of clay and lime after calcination—in the proportion of not less than 35 per cent. of clay and not more

than 61 per cent. of lime—is necessary. If there be too large a percentage of clay, the cement is very quick-setting, and never attains the strength of a more slow-setting composition. A slight excess of lime enables the materials to burn at a high temperature, thus making a slow-setting and strong cement. The Engineering Standards Committee, supported by the Institution of Civil Engineers, Institution of Mechanical Engineers, Institute of Naval Architects, the Iron and Steel Institute and the Institution of Electrical Engineers, in their report dated August 1910, have stated that cement should comply with the following degrees of fineness.

The residue on a sieve $76 \times 76 = 5{,}776$ meshes per square inch should not exceed 3 per cent.

The residue on a sieve 180×180 32,400 meshes per square inch should not exceed 22·5 per cent.

The composition of a thoroughly good Portland cement is :—

	Per cent.
Alumina and Oxide of Iron	12
Silica	23
Lime	61
Magnesia	1
Sulphuric Acid	1·5
Carbonic Acid and Moisture	1·5

Portland cement should always be tested before it is used for considerable variations will be met with even in the best brand. For sewerage works, only the best quality should be used. The most important test for cement is that of tensile strength ; and or this test small quantities should be taken from a number of casks. The samples should then be made into briquettes, one square inch in section at the centre, and immersed in water after seven hours, care being taken that there be no disturbance of the water after the briquettes are immersed. The briquettes should remain in water for periods varying from 7 to 30 days.

Those immersed for seven days should stand without fracture a tensile strain of at least 400lbs. per square inch ; those

immersed for twenty-eight days at least 500lbs. per square inch.

Another test is the sand test. Briquettes made in the proportion of three parts of absolutely clean sharp sand and one of cement should be left standing one day in the mould and twenty-eight days in water; they should then bear not less than 225lbs. of tensile strain per square inch; any less strain would betoken a doubtful cement. Many Engineers prefer this test to the former one, as pure cement is not extensively used.

Rapidity of setting may be judged by the use of a machine known as Vicat's Needle. A pad of cement should not be so set in less than one hour that the needle cannot penetrate it.

The specific gravity of Portland cement, one month after manufacture, should not be less than 3·15.

Before being used, cement should, as a rule, be cooled by spreading it on the floor of a dry room. This also allows the free time which exists in all new cement to slake; if this is not done, there is a likelihood of its "blowing" after the work has set.

Only just so much of the cement as is required for immediate use should be mixed at one time, as once it has commenced to harden it cannot be worked up again. The amount of water necessary in mixing cement varies with different makes, but in should usually be 20 per cent. of the volume of dry material.

Portland cement is the ouly cement that should be used for works that sewage may come in contact with, as it is practically unaffected by acids, should such exist in the sewage. Cement, said to be similar to Portland cement, is now being made in Madras and Calcutta, but the Author has had no experience of it and can therefore say nothing as to its quality.

Sand.—The sand used should be sharp and clean and entirely free from loam or any organic matter. The kind principally used in Bombay is basaltic sand, washed during the monsoon months from neighbouring hills of volcanic formation. The use of sea-sand is undesirable with lime—at any rate, until thoroughly washed in

resh water—because of its liability to sweat in a humid atmosphere, but with cement slight salinity makes no difference.

Lime.—Lime may be divided into two classes :—

(1) (*a*) Fat or common lime, which gains no consistency under water, being only pure chalk without any adulterants.

(*b*) Non-hydraulic lime, which is a combination of lime and non-soluble mineral matter, such as silica and alumina.

(2) Hydraulic lime, which is obtained from lime-stones having a greater or less percentage of soluble silica and alumina.

Fat lime is a rich lime, is found in India, principally in Madras, and contains an excessive quantity of carbonate of lime. It can be usefully employed in whitewashing, plastering, and stucco work, as it takes a good polish.

Non-hydraulic lime is a lime deficient in soluble silica and alumina, and requires the addition of pumice to give it hydraulic properties. Most of the pumice used in India is obtained from Aden, and is a volcanic product.

Probably the best known hydraulic lime in India is found in the form of kankar. Kankar is obtained either in nodules on or near the surface of the ground, or is dug up in large lumps from pits in alluvial soil. Kankar is a species of subsoil tufa, formed by the deposition of calacareous matter extracted from beds of sand and clay in minute quantities and re-deposited in the form of kankar. A good kankar should give the following proportions:—

Carbonate of lime	112 grs.
Clay	9 ,,
Sand	29 ,,
Total ..	150 grs.

An easy test for determining the quality of kankar is to pound 150 grains, so that it will pass through a fine sieve. Add sufficient hydrochloric acid until effervescence ceases and filter carefully through blotting paper. That which remains is clay or sand, or both. The difference between this weight and the 150 grains

represents the carbonate of lime dissolved by the hydrochloric acid. The remainder should be now washed by decantation so as to get rid of the lighter particles of clay until the sand is left, which should be dried and weighed. The difference gives the proportions of clay and sand.

In purchasing lime, it should be remembered that the addition of 10 per cent. of water will give a 30 per cent. increase in measurement—a fact which should not be overlooked in taking over lime or works.

Mortar.—The proportions of sand and cement are usually from two or three of sand to one of cement, measured dry. Cement mortar for joining pipes should be in the proportion of one part of cement to one part of sand. Such cement and sand should be mixed dry before water is added, and care should be taken that water in excess is not used. Sand should be screened and only the finer portion used in cement mortar. Cement mortar should never be ground.

In lime mortar, the best proportion for Indian lime of good quality is two parts (by measure, dry) of lime and three of sand. For hydraulic works and foundations, equal parts of lime and sand should be used ; and in the case of lime being non-hydraulic, the mixture for mortar should be one part lime, one part surki, and one part sand (surki being bricks pounded very finely). As a rule, kankar should not have surki mixed with it : such a mixture gives a weakened mortar. It is not easy to lay down a hard and fast line for the properties of lime mortar : every Engineer should make experiments for himself with the lime of his district. The ingredients for mortar should be well mixed, the lime being previously screened to remove extraneous unburnt matter, and then wetted and ground in a mill, ghanni, or mixing machine ; in the case of a single ghanni being used, it should usually be subjected to at least 160 full rounds of the ghanni stone, or as many rounds as experience may show to be necessary. A ghanni is a simple form of mill and consists of a circular channel, usually 30 feet in

diameter, 1 foot 4 inches wide, and about 1 foot deep, lined at the bottom and sides with flag stones set dry. In the centre is a short vertical post, round which revolves a horizontal bar, to the outer end of which a bullock is yoked. A grinding stone, some 2 feet 6 inches in diameter and 1 foot in thickness, is attached to the bar and is worked round in the channel by the bullock. A ghanni may have two grinding stones attached to two horizontal bars indirectly opposite directions from the central post.

Hydraulic lime mortar should be mixed four parts (by measure, dry) of lime and four of sand, and wetted and ground in a ghanni in the same way as common mortar.

Concrete.—The ingredients for concrete are ballast or gravel, sand, and a cementing material, either Portland cement or lime. When good sharp river ballast can be obtained, it will frequently be found to contain sufficient sand mixed with the stones to be ready for use ; but as this is not always obtainable, broken stone or shingle have to be utilized and sand added to the whole and well mixed. Finer particles of stone are better than sand, if they can be obtained in a sufficient quantity. For cement concrete, a good proportion to adopt is, for the matrix, two parts broken stone, two parts shingle, and two parts sand. The materials can be mixed together and the volume ascertained and then an amount of cement added, which will bring the volume of matrix to cement 4 to 1, 5 to 1, 6 to 1, and so on, according to strength and quality of concrete required. 6 to 1 will make a good quality concrete for ordinary purposes. Cement concrete is much stronger for having stones in it of various sizes from the maximum downwards. The concrete should be mixed on a stage constructed of planks or boards, the materials forming the aggregate being, if necessary, previously washed. The whole mass should be turned over at least twice dry and three times after wetting, so as to become thoroughly intermixed. Water should not be splashed on from a bucket, but carefully added from a large watering pot or hose

fitted with a big rose, as this will facilitate the whole mass being equally wetted. In England it is becoming very general, where large masses of concrete are required, to perform the mixing in a concrete mixer. This consists of a revolving drum provided with a large manhole door. To fill the mixer, the drum is revolved until the manhole door is on the top of the drum. A definite volume of matrix is then put in, together with an ascertained quàntity of water and then the proper proportion of cement is added. The manhole cover is then clipped on and the drum revolved. The manhole is finally opened when at the bottom and the concrete automatically discharges into carts or trucks. By these means absolute control is obtained over the process, and it has been found that an equally strong concrete can be produced with a smaller proportion of cement than by hand mixing. In putting concrete in position, Engineers differ considerably as to the best thickness for each layer and the amount of consolidation, but the Author has found that in India, for ordinary purposes, if the concrete is deposited in layers of one foot, and rammed or punned until the cement just begins to form a cream on the surface, it sets in a perfectly solid homogeneous mass. If the concrete however, is to bear a heavy weight, a less thickness of layers is desirable. The surface of one layer should be thoroughly well wetted and set before adding a second layer, and if any considerable period has elapsed since the first was put down, it should be picked over to ensure a good joint. There is probably no work which requires such careful supervision as the mixing and putting in position of concrete. The materials must be thoroughly clean, and when the correctly measured amount of cement has been added, the mass must be thoroughly well turned over and the proper portion of water added; and finally, the concrete must be sufficiently, but not excessively, rammed when in position. All this can only be ensured by careful and constant supervision. It should be noted that 125 cubic feet of dry materials will form 100 cubic feet of solid concrete.

A rough and ready method of gauging the best proportions of broken stone and sand for good concrete, and one which can be adopted by any one without difficulty, is as follows :—

An ordinary bucket should be filled with broken stone, level with the top, and as much water poured in as the bucket will hold: this quantity of water represents the whole of the space between the interstices in the stones, and when poured off and measured, will give the proper portion of sand to be added : the sand can then be added and the bucket refilled in the same way, and the water again occupying the interestics will represent the minimum amount of cement to be used. In actual practice, it is advisable to keep the quantity of cement somewhat in excess of the amount gauged by this method, so as to ensure every particle of the aggregate being thoroughly cemented together. This method should be employed only so far as the stone and sand are concerned, as the former varies in size in different localities, and even if broken by hand is not always uniform. The proportion of cement should be fixed in accordance with the nature of the work and quality of concrete required. The quantity as ascertained by the method described, however, should under no circumstances be reduced, as the concrete will not otherwise be uniform or properly cemented together.

Stone for concrete should be broken to a size not larger than would pass through a 2-inch ring.

Common lime concrete should be made of one part of lime mortar and two parts of broken stone.

Hydraulic lime concrete should be made of three parts of mortar four parts of shingle, and four parts of broken stone.

When concrete is being laid in such a position that it is to be more than two feet in thickness, it is admissible to allow rubble tones not exceeding one-half a cubic foot in size to be inserted in the concrete ; but in such cases no stone should be laid nearer than nine inches from any other in any direction, nor nearer than nine inches from the surface.

Bricks.—Bricks are made of tempered clay, formed in moulds to the requisite size and shape and then burnt in a kiln. The outsides of bricks made of clay deposited with salt show dampness in humid atmosphere and require to be painted. All bricks for sanitary purposes should be made of the best quality procurable and of uniform colour with a hard impervious surface. A simple test for hardness is that a finger nail should not be able to make a scratch or mark on the surface. The principal test for bricks is that of absorption, and Engineers generally lay down that a brick of good quality should not absorb more than 10 per cent. of its dry weight after 24 hours' immersion in water. Another test known as the crushing test is that a brick should resist the weight of 500 lbs. per square inch. All bricks should ring well when struck, be table-moulded, sound, hard, regular, well burnt and with straight sharp arises, and should not vary from the standard size.

Stone.—Building stone is classed under three heads, namely, siliceous, argillaceous, and calcareous.

Stone is rarely used in sewerage works, and the Sanitary Engineer may have little occasion to deal with this material, except for pumping stations and other buildings; but if it be found requisite, care must be taken that none with vents or flaws or traversed with seams or of perishable material should be used.

The principal kinds used in Bombay are basaltic trap or blue stone, Kurla yellow trap, both being siliceous stone, and a light coloured building calcareous stone known as Porbunder stone. Any of these are suitable for building, but basaltic trap is the best. The absorption of basaltic trap is very small, being 0·30 per cent. of its dry weight, while that of Kurla yellow trap is as much as 4 per cent.

Pipes.—It is not more than seventy years since earthenware glazed pipes were first used for sewers in the British Isles, but during that period their manufacture has become one of the great industries of the country.

Earthenware pipes consist of two kinds, stoneware and fireclay.

Fire clay pipes, though less brittle than stoneware pipes, are not considered, thickness for thickness, as strong or as durable as the latter. They also usually possess great absorptive power which is fatal to their use. Stoneware is therefore generally specified by Engineers for sewerage works.

Stoneware pipes of a greater diameter than 18 inches are rarely used, as well-shaped pipes exceeding this size are difficult to construct and are consequently expensive.

The qualifications of a good stoneware pipe are that it should be perfectly straight, truly cylindrical, thoroughly salt-glazed and burnt, and free from cracks, flaws, and defects of every description. Every pipe should be finished with a perfectly smooth interior.

The Engineering Standards Committee, in a report published in June 1914, have laid down the following tests for salt-glazed ware pipes.

The standard length of the barrels of straight pipes shall be as follows :—

Up to and including 6 ins.	2 ft.
7 ins. to 10 ins. inclusive	2 ft. and 2 ft. 6 ins.
12 ins. to 36 ins. inclusive	2 ft., 2 ft. 6 ins. and 3 ft. as may be specified.

The interior of the sockets, and the exterior of the spigots for a length equal to $1\frac{1}{2}$ times the depth of the sockets, shall be grooved, and the depth of such grooves shall be not less than one-sixteenth of an inch.

The glazing shall be obtained by the action of the fumes of volatilised common salt on the material of the pipes during the process of burning. The glaze shall cover the interior and the exterior surfaces of the pipes, which will remain exposed after jointing.

A variation in the thickness of the barrel at any two points is not to exceed the figure given in the following Table :—

Not exceeding 12 ins. diam.	1-16th in.
13 ins. to 18 ins. diam. inclusive	3-32nd ,,
Above 18 ins. to 36 ins. diam. inclusive	1-8th ,,

The mean thickness of the barrel of any individual pipe shall be ascertained by adding the measured least thickness to the greatest thickness and dividing the sum by two.

Subject to the mean thickness of the socket of a pipe being not less than that specified, a variation in thickness of the socket at any two points not exceeding the figure given in the following is permissible :—

Not exceeding 12 ins. diam.	1-16th in.
13 ins. to 18 ins. diam. inclusive	3-32nd ,,
Above 18 ins. to 36 ins. diam. inclusive	1-8th ,,

The mean thickness of the socket of any individual pipe shall be ascertained by adding the measured least thickness to the greatest thickness and dividing the sum by two.

The pipes when subjected to the hydraulic test must withstand an internal hydraulic test pressure on the barrels of the pipe of 20 lbs. per square inch without showing signs of injury or leakage. The pressure shall be applied at a rate not exceeding 10 lbs. per square inch in five seconds, and full pressure shall be maintained for at least five seconds. Care shall be taken that all air is extracted before the test is commenced.

Absorption Test.—The test pieces selected for testing shall be taken from the body of the pipe and not within six inches of the end. Each test piece shall be of the whole thickness of the pipe, and shall have two glazed surfaces, each having an area of not less than 8 inches super nor more than 20 inches super. The test pieces shall be dried at a temperature of not less than 150° C., until no further loss of weight can be noted. They shall then be immersed in cold water, and the temperature raised to boiling point (100° C.) The water shall be maintained at that temperature for one hour, and after it has been allowed to cool, the test pieces shall be removed, carefully wiped with a dry cloth, and then re-weighed. The percentage increase in weight of each test piece by absorption of water shall not exceed the figures given in the following Table :—

Thickness of pipe.	Percentage of increase in weight.
$\frac{3}{4}$ in. and under	5%
Over $\frac{3}{4}$ in. and up to 1 in.	6%
,, 1 ,, ,, $1\frac{1}{2}$,, ...	8%
,, $1\frac{1}{2}$ in.	10%

One absorption test to be made to every hundred pipes.

The impermeability of a pipe may be taken as evidence of its durability and fitness for sewerage works. The more impervious a pipe is, the better will it prevent the entrance into its interestices of those agents which are likely to exercise a destructive influence upon it; for the chemical action of certain materials found in sewage will sooner or later destroy the pipe.

As pipes made of clay containing lime are found to fail when laid in wet ground, it is desirable to test the material of which the pipe is made. For this purpose the following method will be found satisfactory. Pulverize a small piece of the pipe, weigh and boil in hydrochloric acid; subsequently wash on a filter and dry, noting any loss in weight. If there is no loss in weight, then the material may be considered free from lime.

The tests which the Author usually lays down are:—

(1) That a piece about 2 inches square from any part of the pipe shall not absorb, after 48 hours' immersion in water, more than 2 per cent. of its own dry weight of water.

(2) That the pipe shall be capable of resisting a bursting pressure of 30 lbs. per square inch.

(3) That the breaking weight of the pipe shall not be less than 1,700 lbs., applied by means of a lever or otherwise to the centre of a flat board of hard wood, of the same length as the pipe, laid along the top of the pipe throughout its length exclusive of the socket. The pipe, when subjected to this test, should be supported on a similar flat board underneath, the socket overhanging, and a layer of felt being laid between the pipe and the boards.

The salt-glazing of a pipe is a very important feature in its manufacture, for it permeates the whole of the material. Other forms of glazing often merely hide the defects of a worthless material and some pipes, though apparently of good quality, by reason of their shape, colour, and glaze, and which also ring well, are of the worst possible material.

In England, pipes varying from 18 to 36 inches in diameter are often made of cement. Such pipes are now largely specified and used by leading Sanitary Engineers for sewerage works, and they continue to grow in favour. It is desirable in the case of cement pipes to surround them with concrete, a minimum thickness of 4 inches being usually sufficient. Cement pipes have an advantage in that they can be made absolutely circular and straight. The best English Portland cement should be used in their manufacture, and that only after careful and stringent tests. In a cement pipe there is no projecting socket, the joint being contained in the thickness of the pipe itself; it is usually made with a wipe of cement.

A disadvantage of cement pipes is that junction pipes are difficult to construct, while to make a junction between a house connection pipe and a cement sewer by merely cutting a hole in the latter, is a crude and unsatisfactory piece of work. The socket also as at present made is shallow, and if the pipes are not very carefully laid, the joints are liable to separate through pressure of the earth.

An instructive failure of cement pipes has been brought to notice in Madras. Previous to 1902, the Madras Municipality used only stoneware pipes in their sewerage system; but early in that year they decided, on the score of economy, to use locally-made cement pipes up to 9 inches in diameter. Some five years later, these cement pipes were discovered to be in a very curious condition: that portion of the pipes which was generally covered by sewage seemed to have stood satisfactorily, but the part exposed to sewer gas had corroded to the extent of collapse. Lieutenant-Colonel J. VanGuyzel, I.M.S., Chemical Examiner to Government, to whom the matter was referred, gives the following percentages of the corroded parts of the pipe :—

Silica	46·7
Calcium Sulphate	43·06
Uncombined Lime	0·38
Alkalides and Sulphur	0·39
Moisture	9·45

The corroded parts were occupied by a soft and easily removable substance which gave the above analysis.

Lieutenant-Colonel VanGuyzel's explanation is as follows :—

> " The calcium silicate is one of the important ingredients of cement. When the sulphuretted hydrogen which is present in the sewage comes in contact with the portion of the cement pipe which is not covered by the sewage, it decomposes the calcium silicate and forms calcium sulphide and free silica. The calcium sulphide again in the presence of moisture gets converted into calcium sulphate and in the process deposits a small quantity of free sulphur. This reaction accounts for the presence of the soft substance, the chemical composition of which I have already given."

The above explanation is very clear and is doubtless correct.

There is very little difference in the composition of good Portland cement and that of cement made in Madras as given by the published analysis.

The excess of free silica found by Colonel J. VanGuyzel is possibly due to added sand in the construction of the pipes.

Cement pipes in other parts of the world, however, have given great satisfaction, and after many years use have been found in perfect condition.

The silicated stone pipe is another form of pipe, but it requires great care in manufacture, is expensive, and so far is not in very general favour among Sanitary Engineers.

Cast iron, though probably the best class of conduit for sewage, is too expensive for the purpose, except under special circumstances.

The junctions of the stoneware pipes are to be made each with two laps or rings of tarred gaskin forced well into the bottom of the socket, and the remaining space filled with Portland cement which must be brought outside the end of the socket so as to form a ring or fillet ·04 metre wide and ·012 metre deeper than the

socket space, the cement to be mixed with an equal proportion of clean sharp sand.

Patent Joint Pipes.—There are many patent jointed stoneware pipes in the market which, under certain conditions serve a very useful purpose; but they are naturally much more expensive than ordinary stoneware pipes. The following is a description of a few of these:—

The Stanford Joint, as shewn in Fig. 3, is similar in construction to the turned spigot and faucet joints of cast iron pipes

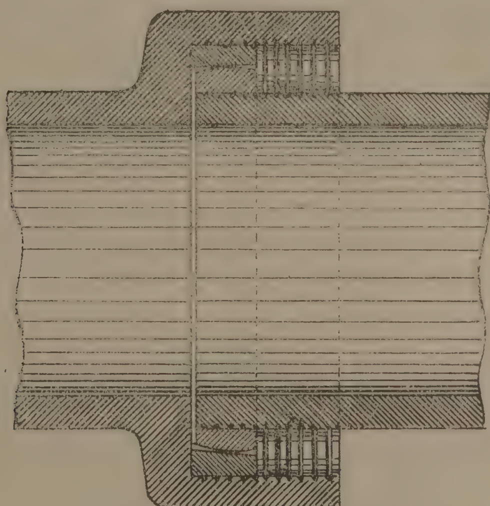


FIG. 3.—IMPROVED STANFORD JOINT.

being formed of turned rings of a durable material generally consisting of a composition of sulphur, tar, and ground earthenware. These rings, which are spherically shaped, exactly fit into each other, being counterparts; and, in order to allow of some play, the sockets are slightly concave and the spigots slightly convex. The complete joint is made by grooving the rings, and it is claimed that a perfect joint is made thereby.

Doulton & Co. have a patent self-adjusting pipe (Fig. 4) for which it is claimed that no cement is required for jointing purposes, the grooves being merely greased or tarred.

The pattern shewn in Fig. 5 is another joint manufactured by Messrs. Doulton & Co. for those who prefer to have a more steady joint.

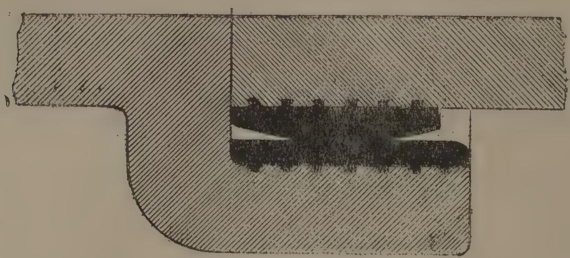


FIG. 4.—SECTION OF SELF-ADJUSTING JOINT.

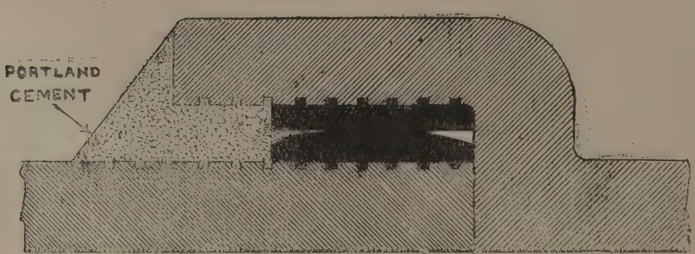


FIG. 5.—SECTION OF COMPOSITE JOINTS.

The Hassall Improved Patent Safety Joint, shewn in Fig. 6, is a joint largely used. The rings are cast on with the idea of centering the pipes and retaining them in position, while the operation of filling with Portland cement is being effected. Plastic is applied to the end of the spigot and between the surfaces of the bituminous rings, so as to have a cushion to embed them and render harmless any grit that may have got there and to prevent the cement from running into the pipe. The groove is filled with Portland cement. This is a good joint and has successfully stood

the test of several years. Many pipe-makers in England hold a license to manufacture pipes on this principle.

Fig. 7 is a drawing of Syke's Patent Joints. On the spigot and the socket of each pipe are formed, in bituminous composition, a male and a female screw, in such a manner as to give a little play in adjusting the joint, so as to secure flexibility without interfering

Hassall's Patent Joint.

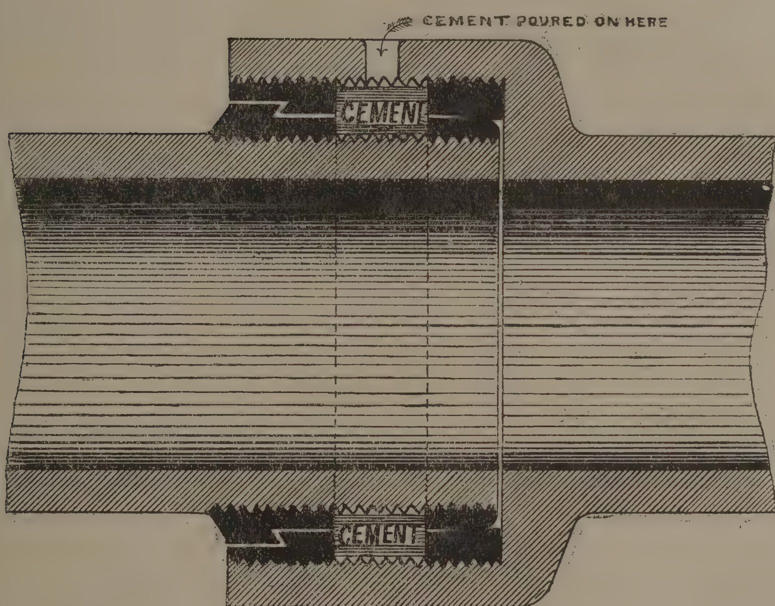
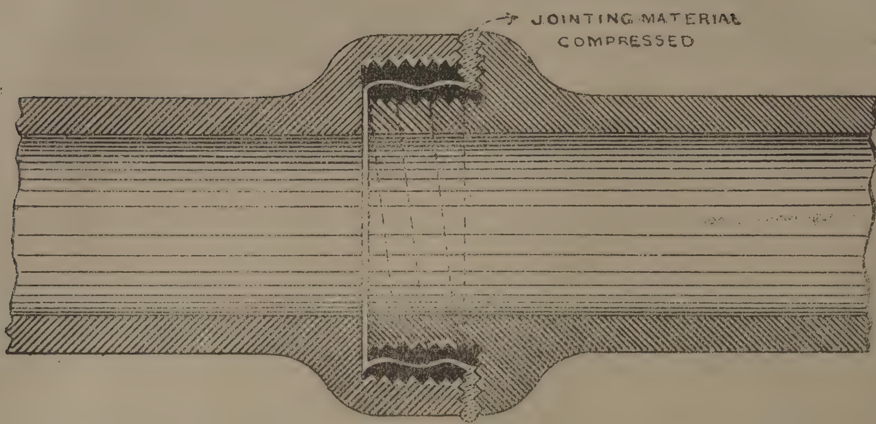
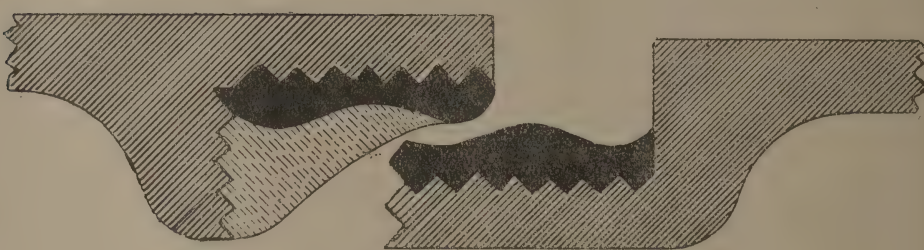


Fig. 6.—Section.

with the proper level of the pipe when laid. The spigot is also provided with a strong collar or ring, against which, when jointing the pipes, a fillet of cement composition is placed, which is compressed between the end of the socket and the rim by the act of screwing the pipes together. The pressure forces the superfluous cement composition into the space left for play in the thread. It is claimed that these joints have stood an hydraulic test



SYKE'S PATENT JOINTS.



BEFORE JOINTING.

FIG. 7.—AFTER JOINTING.

of 140 lbs. per square inch without leaking. The pipes are made by the Albion Clay Company.

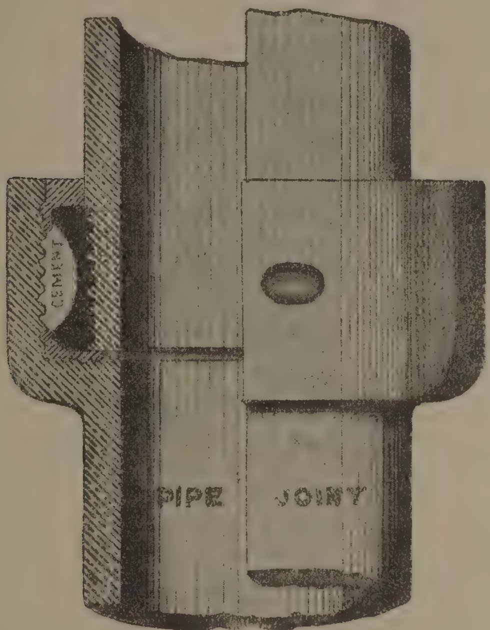


FIG. 8.

A patent joint adopted for stoneware drain pipes was introduced by the late Mr. John Parker and is known as Parker's Safety Pipe Joint (Fig. 8). This joint has only one composition ring instead of two, as is common to most patent joints, thus reducing the cost. The method of jointing is as follows:—The collar has a cushion of tempered clay which receives and embeds the composition ring on the spigot end, making it water-tight while the cement is poured into the anular groove. The band of tempered clay round the mouth of the socket after the pipes are in position, prevents the Portland cement from escaping outwards.

The Sutton Patent Joint (Fig. 9) is in many ways similar to the Hassall, but it is said to be a slight improvement on it. In this joint also plastic is used, but the liquid cement is pumped in through one of the two openings in the socket of the pipe by means of a simple and cheap hand-pump, until it appears through the other opening, when the joint may be considered to be successfully made.

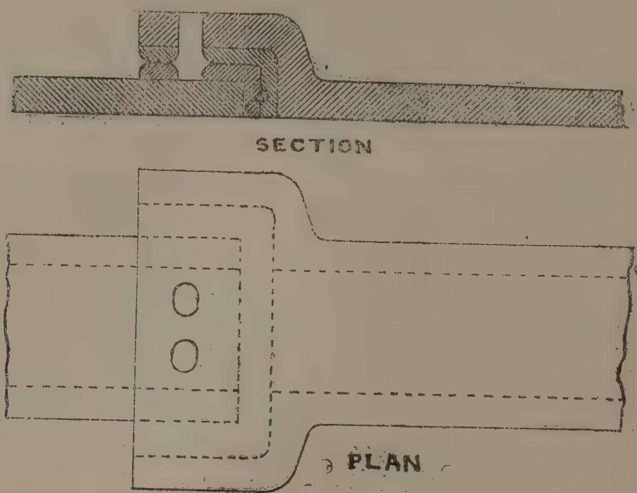


FIG. 9.

Pipes with the last described joint have been used with success in Bombay in positions where, owing to running water in the trenches, it would have been impossible to make the ordinary cement joint with safety. Pipe layers in India are very conservative, and have a strong objection to patent joints, but after a little practice they are able to make two joints with patent pipes in the time they would require to complete one ordinary joint.

Wherever trenches are water-logged and cannot be kept free of water, an Engineer does wisely to spend the extra money in using good special joint pipes, being thus assured of good watertight joints and running no risk of permanently leaky joints.

In Eastern countries where the Banyan tree (*Ficus Indica*) is largely grown for its shade along road sides and streets, much trouble is avoided by the use of patent jointed pipes, for the roots of the Banyan cannot be prevented by ordinary cement-joints alone from piercing the pipes in their search for water. The mixture of tar and cement, which is sometimes used for jointing

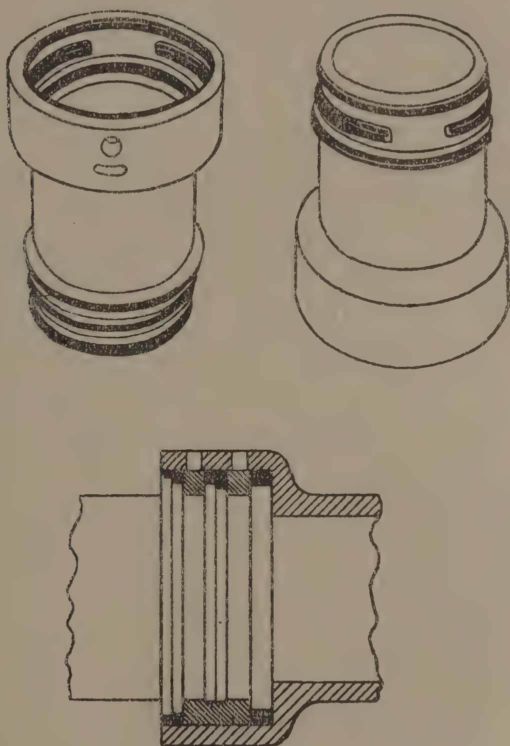


Fig. 10.

sewers in streets where Banyan trees flourish, has only been partially successful in Bombay; but no Banyan root as a rule can find its way through a good patent joint pipe.

In recent years Messrs. Wragg & Sons, Ltd., Swadlincote, have placed on the market two reliable patent pipe joints. The first is known as the Keeptite Joint with a treble seal.

The joint (Fig. 10) consists of two Chambers formed in the usual way with bitumen composition, these two Chambers are made to communicate with each other at the lowest point of the joint, and are ventilated at the highest points, so that, as the cement grouting is fed or introduced at the highest point of one Chamber, the same will in its flow dislodge any air or water which might in the ordinary way have become locked in the Chamber.

The cement grouting passing from the first Chamber to the adjoining Chamber has to fill up from the bottom until the vent openings are reached, the high specific gravity of the grouting causing it to drive all water and air before it. The one Chamber acts as a conduit to the adjoining Chamber, and when complete a triple seal joint is the result.

During the laying of one length of main sewer the time was taken of the men engaged, 42 joints were made in in 52 minutes, and 61 joints in 90 minutes. The larger number, *viz.*, 61, were laid during heavy showers of rain, and with a quantity of water in the trench and in the joints before running.

There is no doubt that this joint is theoretically the finest joint on the market, but it requires a certain amount of skilled labour to lay it; if that is not obtainable an irregular line of pipe is apt to result. Great care is required in laying the pipe dry in the first instance, and of placing the plastic clay on the inside of the joint to prevent the grouted cement from running through the joint into the pipe.

Many hundreds of these pipes were laid in connection with the Cairo and Port Said Sewerage Schemes, and where proper care was taken they were very successful, and as in both these towns these trenches were usually water-logged absolutely water-tight joints were required, and were obtained by the Keeptite Joint.

Another useful joint is Messrs. Wragg & Sons' corrugated socket pipe. (Fig. 11.)

The main object of this pipe is to form a perfectly true invert. A large percentage of the stoppages in drains and sewers arise

from the irregularity of the invert, caused by the settlement of the spigot within the socket. Sometimes a pipe-layer, in order to avoid this, will prop up the spigot in the socket with pebbles or pieces of tile, yarn, etc., but this is not a reliable method of adjustment.

The invention consists of corrugating the socket, and again re-corrugating the corrugations so as to allow of the surrounding

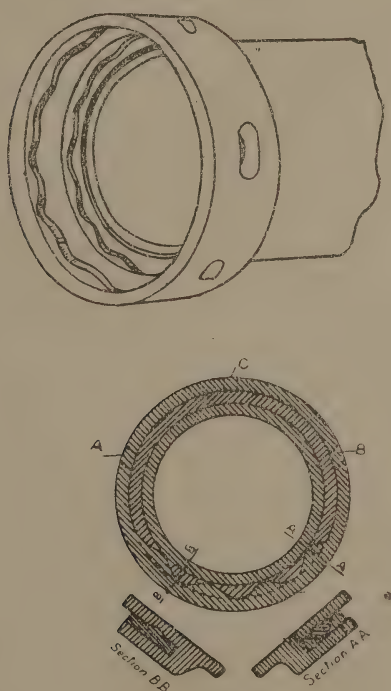


FIG. 11.

of the spigot with an ample supply of Portland cement to secure a good sound joint and it will be noticed that by this contrivance the spigot end of the pipe will rest on knife edge points in the socket all the remaining space being occupied with Portland cement. The invert cannot be other than perfectly true because the space between the top of the corrugations, and the invert line of the

pipe, corresponds with the thickness of the metal of the pipe which rests upon it, as shown by the section.

For jointing the pipe, place a band of mastic clay on the shoulder of the socket of the pipe, sufficiently thick to prevent the liquid cement running inside the pipe. Then insert the spigot of the next pipe, taking care that the corrugations are always at the bottom, so as to be in position to receive the next pipe. Then close the mouth of the socket with a suitable length of rope, against which put a strong backing of clay (the ropes may be removed for

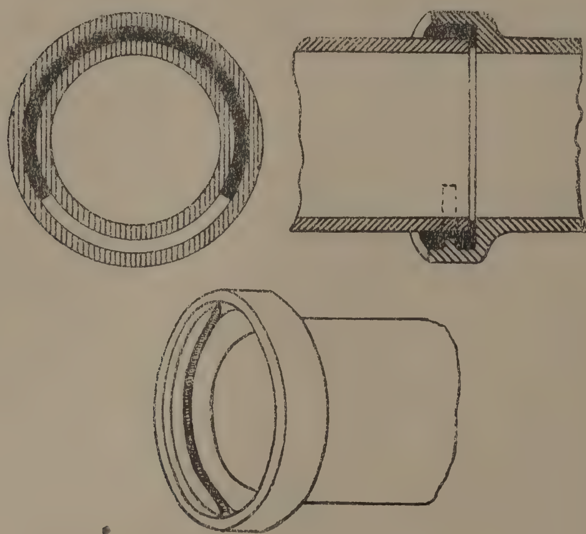


FIG. 12.

further use as soon as the joints are set). Pour neat Portland cement grout through hole A till it appears at hole B, then leave it for a few minutes ; in the interval other joints can be dealt with in the same way, by which time the cement first run will be sufficiently set to receive the remainder without fear of bursting out the clay backing. Pour gently through hole C till the crown portion of the joint is completed. Pull the clay band away a little at the top so as to let the air out while pouring in the cement.

It is recommended that a clay cup be put round the holes, A, B, and C, to facilitate the receiving of the cement.

It is scarcely necessary to add that in the event of any of the clay being squeezed into the pipe it must be carefully raked out in the usual manner.

Another pipe worth mentioning is the "Velvert" Pipe (Fig. 12). The purpose of this pipe is to secure in an inexpensive way, concentricity, a truer invert, and a better sealing space than can be obtained in the ordinary spigot and socket pipes. This is accomplished by the insertion in the sockets of the pipe of a rest-piece of stoneware, which forms part of the socket and extends for nearly one-third of the way round the socket, leaving room for jointing material on both sides of it.

Large numbers of these pipes were used in the Cairo Drainage in dry trenches, and where no special skilled labour is available, the use of this pipe guarantees a true alignment, a most important thing in the reticulation of a sewage scheme.

Another joint which was used with great success in the Cairo Main Drainage, is Messrs. Doulton's "Grouted Composite Joint." (Fig. 13.) This joint has two distinct features, an inner seal formed by two bands of composition, one cast on the spigot and the other in the socket of the pipe, and an outer seal of Portland cement which is applied in the form of a grout.

The inner seal of this joint consists of the Makers' Self-Adjusting Joint, and its usefulness is not restricted to preventing the escape of grout into the pipe, a most important matter in the laying of stoneware pipes, but accurately centers the pipes one with another and permits adjustment in laying, another important factor. The outer seal is formed by a band of canvas enclosing the space between the end of the socket of one pipe and a collar on the spigot of the adjoining pipe. One edge of the canvas band is attached to the socket and the free edge is threaded with a binding wire which is operated in a very simple manner. For jointing, the spigot is

fitted into the socket, after a little lubricant has been applied inside the socket and around the spigot, and the free edge of the canvas band is secured behind the collar on the spigot by means of the binding wire; to operate the wire draw tight the end which passes through the loop while still taut, and bend it back over the loop. Cement grout is poured in at the opening at the top until the joint is complete. The canvas being a porous material, cannot maintain an air lock. Water in the trench does not impede the operation of grouting, as the grout displaces any water which is

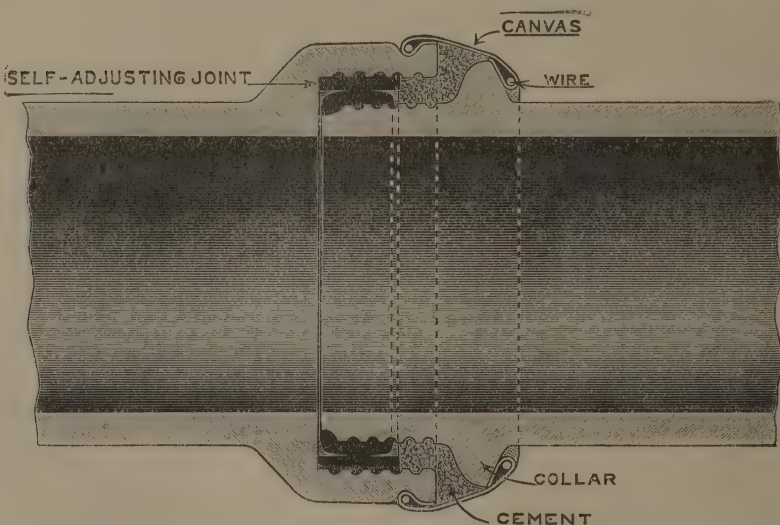


FIG. 13.—HORIZONTAL SECTION.

inside the canvas, and the cement is protected by the canvas band from being disturbed by water.

The pipes are supplied by the Makers with the composition cast on, and each pipe protected at the joint to prevent its being broken in transit.

Another joint of Messrs. Doulton & Co. is the "Simplex Joint" (Fig. 14). This joint is a cheaper type of the Firm's "Grouted Composite Joint." The joint has no composition on the inside of the socket, but its place is taken by a roll of clay or mastic,

whose function is to prevent cement escaping through the joint into the pipe. The annular chamber to receive the grout is formed, as in the Composite Joint, by a band of canvas, and the canvas is operated in the same way as described for the Composite Joint. The cement grout is poured into the opening at the top until the joint is complete.

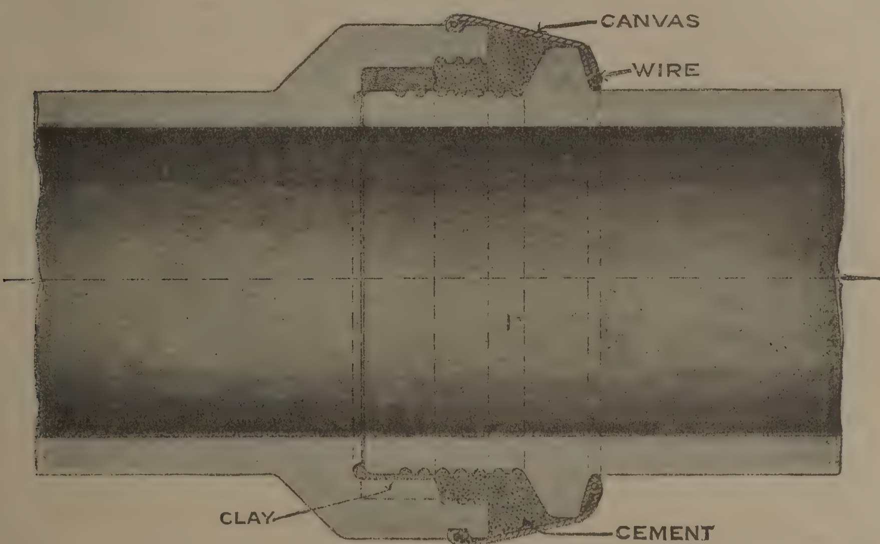


Fig. 14.—Vertical Section.

The Simplex joint is especially suitable for export to tropical climates since there are no composition rings in its construction to sustain damage in transit or to become softened through tropical heat.

Construction.—It is most necessary that sewers should be laid straight and true, with a regular and uniform gradient. Too much importance cannot be attached to this; for once the sewer is laid and the trench filled in, it is lost to view and inequalities in gradients are not easily detected. The proper laying of the sewer can only be ensured by the use of sight rails and boning rods. Sight rails consist of two uprights fixed on either side of the trench with a straight cross rail attached to them horizontally;

they are placed at convenient distances along the line of the sewer and the levels of the cross rails are so fixed that their upper edges are on a plane parallel to the gradient of the sewer, and at a constant height from its bed. If the boning rod (the head of which is like a T square) of a length equal to the above height is moved along the line of sight between the two sight rails, the lower end determines the level of the invert of the sewer. Three sight rails rather than two should be used for one stretch of sewer, and they should be constantly checked to see that they have neither settled nor been moved. In laying pipes, care should be taken that they are laid on an even bearing; for if laid on a point of rock, sooner or later they will fracture and possibly subside, and at any rate will allow sewage to soak into the soil. If laid on a rocky foundation it is advisable to bed the pipes on an even cushion of 2 inches or so of muram.

In drainage contracts, it will be found satisfactory, where ground is of uncertain quality, to lay down in the specification that the width of the trench which will be measured for 9 inch pipe sewers shall be 3 feet. A general rule may, however, be adopted that all trenches shall be at least 2 feet wider than the greatest diameter of the pipe.

The sides of the trench should be carefully secured and shored, whenever the excavation has to be carried to a great depth. No hard and fast rule can be laid down for the maximum depth to which the excavation should be carried without the trench being shored, as this entirely depends on the character of the soil, and on the latter also depends the kind of shoring to be adopted. In reclaimed ground, it will be found dangerous to excavate deeper than three or four feet without shoring; while in good muram, a trench can be dug to a depth of seven or eight feet without any necessity for protection against collapse. Subsoil water also governs this question. A dry soil which will stand without shoring will require, if there is subsoil water running into the trench, to be shored. Of all excavations, the worst and the most difficult is

that of running sand. Three principal kinds of shoring may be adopted, and are shewn in Figs. 15, 16 and 17.

In Fig. 15 the shoring is of the simplest kind. The timbering in this case, if it slips at all, must tighten up against the side of the trench, the excavation being wider at the top than at the bottom. The walings (W) are kept in position by struts (S), and props (B) are in some cases added. In instances where it is desired to support a large surface of ground, poling boards (P) are put in as in Fig. 16. In bad ground, close shoring, as in Fig. 17, is necessary and the poling boards are used as runners. In such shoring the struts should be of as great a diameter as possible; for, if small, they have a tendency to split the walings: the distances between them vertically should be about 5 feet.

It is necessary for the proper and efficient execution of sewerage works that the trenches or excavations should be quite dry, and pumping must, therefore, be employed wherever water is met with. No brickwork should be built, no concrete deposited, and no pipe joints made in water. The water must be kept down by the pumps to below the level of any work, and pumping continued until and as long as may be necessary for the cement to have set hard.

If the bottom of the trench is soft and muddy, it is unsuitable for sewerage works without additional foundation being provided to carry the pipe or sewer. The best expedient to be adopted in such cases is to cause dry rubble to be rammed in the bottom of the trenches as deep as possible, and on this bedding of stones the sewer should be laid or constructed with a layer of good muram or concrete between.

Ovoid Sewers.—Fig. 18 shews the section of an ovoid or egg-shaped sewer, 2 feet 6 inches by 3 feet 9 inches. The invert of the sewer is formed of blocks of cement concrete, carefully and properly moulded in boxes to the form and dimensions required. The concrete for the blocks is composed by measure in the proportion of one part of cement, two parts of sand, and two parts of

METHODS OF SHORING TRENCHES.

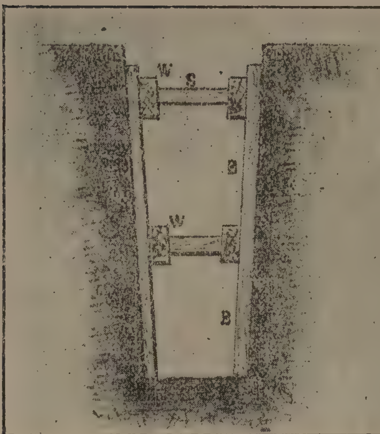


FIG. 15.

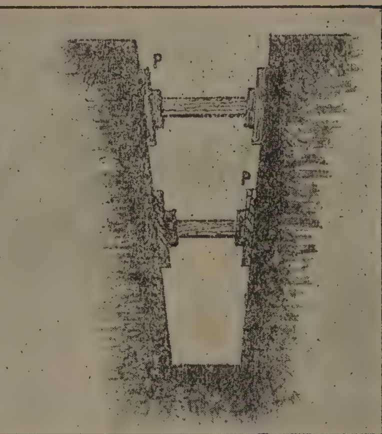


Fig. 16.

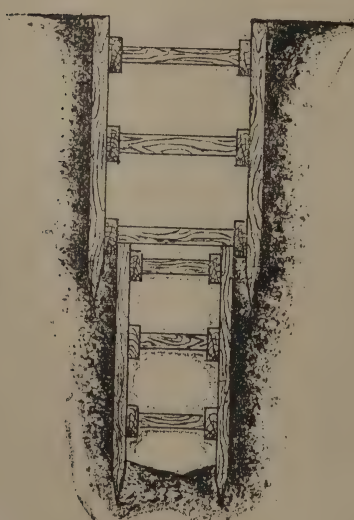


FIG. 17

clean river shingle. The concrete, as soon as mixed, is filled into the mould boxes and well rammed. The blocks should remain in the moulds for two days and be kept well moistened with water. They are then taken out and kept in the shade for several days.

SECTION OF OVOID SEWER 2′-6″ × 3′-9″

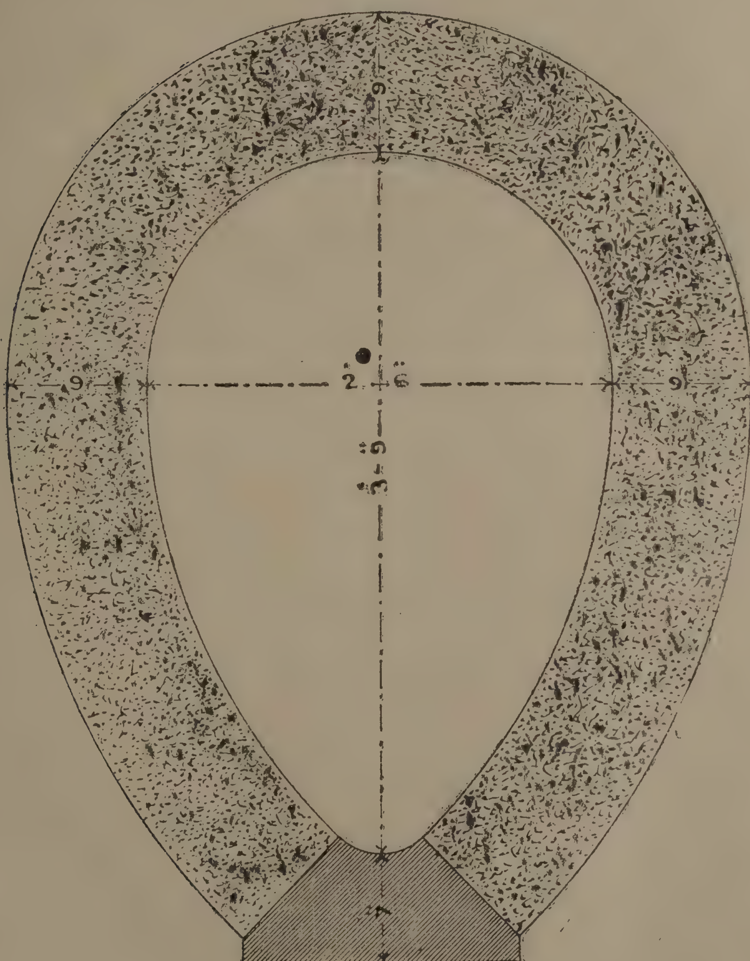


FIG. 18.

before they are used in the work. The blocks should be laid as close together as possible, and the joints should be filled in with neat cement mixed to the consistency of cream.

The excavation for an ovoid sewer between the invert and the springing line should, as far as practicable, be cut to the shape of the sewer. The walls of the ovoid sewer, between the invert and the springing line, may be constructed of cement concrete deposited and well rammed between the sides of the trench, shaped as already described, and a centering formed to the true internal shape of the sewer, allowing half an inch for a facing of cement plaster. After the concrete is set and the centering removed, the internal face is rendered with cement and sand mixed in the proportion of one to one. The covering arch is also formed of cement concrete, rammed *in situ* and plastered on the inside with cement.

In the new form of ovoid sewer, the vertical height is one-and-a-half times the transverse diameter, *i.e.*, three times the radius of the covering arch. The invert is struck from a centre on the vertical height with a radius equal to one-eighth of the transverse diameter, and the sides are struck from centre on the prolongations of the transverse diameter with a radius equal to one-and-a-third times the length of that diameter; while in the old form of ovoid sewer, the radius of the invert is one-fourth of the transverse diameter and that of the sides one-and-a-half times the transverse diameter.

Another not unusual construction for ovoid sewers is that of double brickwork set and rendered in cement as shown in Fig. 19. In this class of sewer, concrete blocks are also advisable for the invert. A simple formula for ascertaining the thickness of brickwork required is :—

d = depth of excavation in feet

r = the external radius of the sewer in feet.

FIG. 19.

Then the thickness of the brickwork in feet is $\frac{dr.}{100}$

An allowance of 50 per cent. should be made on the results of this formula for Indian made bricks, because such bricks are generally much inferior to English, both in shape and quality. For this reason cement plastering, both on the inside and the outside of sewers built with Indian bricks, is necessary to finish the sewer off with an even face, unless concrete is used as a cover or hood, and then cement plastering only on the inside is required. With English bricks, only pointing of the inside face is necessary. With ovoid sewers built with Indian bricks of a size 2 feet 6 inches by 3 feet 9 inches in solid ground not exceeding 20 feet in depth, the thickness of the sewer should be two bricks thick or one brick with a hood of 6 inches of lime concrete. For sewers not exceeding 4 feet in diameter, the thickness should be of two bricks with a cover of 6 inches of lime concrete, the thickness of the brickwork increasing proportionately to the size of the sewer.

Fig. 20 shews an avoid sewer only one brick thick, enclosed entirely with concrete. This type is useful in indifferent ground and at considerable depths.

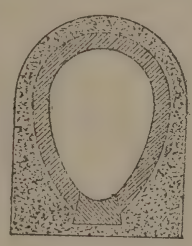


FIG. 20.

In some sewers constructed of concrete the arch is formed of concrete voussoirs, as shewn in Fig. 21. The voussoirs are made in moulds in the same way as the blocks described in regard to Fig. 18. This is a useful construction of sewer and is recommended in bad ground on account of its strength.

Fig. 22 shews another type of ovoid sewer, known as the new egg-shaped, and is for use in gravel or running sand. The invert blocks may be of concrete or stoneware. It will be noticed here that the lower half of this sewer is well protected with a covering of cement concrete.

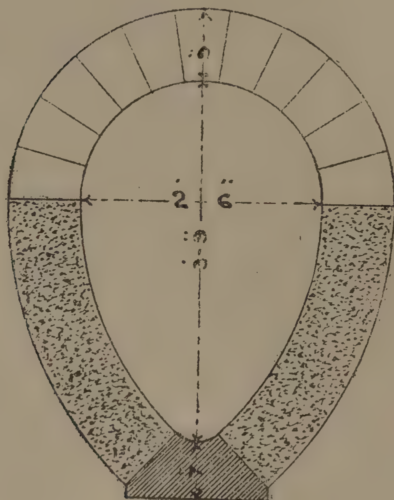


FIG. 21.

In recent years circular brick sewers have found greater favour among Engineers than ovoid or egg-shaped sewers There are several reasons for this, the principal being that circular sewers of a large size are rarely called upon to deal with so little sewage as to make an egg-shaped sewer of similar capacity advantageous. Again, the length of the wetted perimeter of a cir-

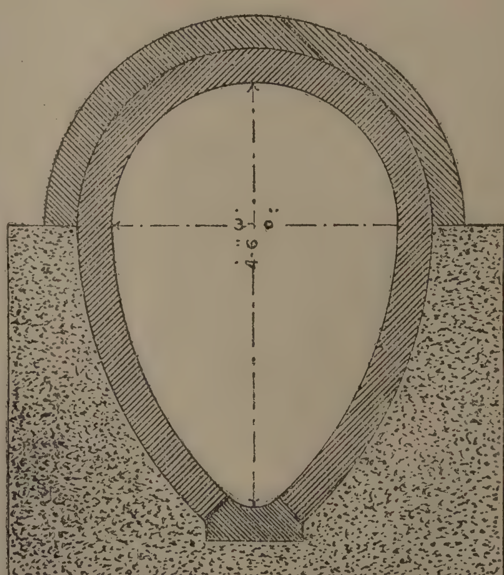


FIG. 22.

cular sewer is, with equal volumes of sewage, less than that of an egg-shaped sewer: circular sewers are also usually more economical in construction.

Stoneware junction blocks, of the shape shown in Fig. 23 are inserted in the wall of the sewer above springing level, wherever required, for connections of house drains.

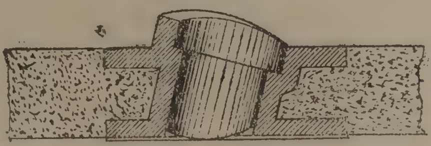


FIG. 23.

Plate 2 shews a design for manholes for ovoid sewers. These may be built either of concrete or of brickwork set in cement or hydraulic mortar, and rendered both internally and externally with cement plaster. Cast-iron steps are inserted in the manhole, so as to give access to the sewer when required, with a notch in the wall in lieu of the last step, as any projection at this level would be liable to catch rags, etc., and cause obstruction to the flow of sewage. In certain manholes a groove is left in the invert and walls for flushing purposes as shown in Plate 2. Into this groove a wooden door is let down and kept there until sufficient sewage is dammed up to give a good flush. The manholes are covered with cast iron frames and covers as hereinafter described.

Laying and Jointing of Stone-ware Pipe-Sewers.—Pipes should not be laid at too great a depth without a protection of concrete designed to resist the pressure of the covering material. A depth of 15 feet to 16 feet is recommended as the limit for 9-inch pipes and 12 feet for all larger sizes; and all pipes laid at these or greater depths should be laid on and covered with a layer of 6 inches of lime or cement concrete. Pipes which are laid at a shallow depth may also require a protection of concrete to prevent rupture by the weight of heavy traffic.

It is a good rule to follow that the minimum depth at which a pipe sewer should be laid should be equal to three times the diameter of the pipe. If circumstances are such that this rule

cannot be followed and the sewer must be laid at a less depth a cast iron pipe should be used.

In the laying of pipe sewers, the pipes should be first laid and fitted dry, previous to the jointing being commenced, such junctions being inserted as may be required for house drainage connections. Pipes should then be plumbed and boned to ensure their being truly laid both to line and gradient.

In earlier years, stoneware pipes were jointed merely with clay. No worse material than clay can be found for jointing pipes; for a soft yielding substance of this description is almost certain to be washed out of the joint either by water escaping from the pipes or by the subsoil water flowing alongside the pipe. Moreover, a material such as clay is sure to be pressed from the joint by the weight of the earth covering the pipe. Clay also offers no barrier to roots entering the pipe through the joint.

Stoneware pipes for conveying sewage should always have their joints composed of cement mortar, *i.e.*, one of cement and one of fine sand. The process of jointing should be as follows:— A gasket of hemp, well-tarred and cut in lengths sufficient to pass completely round the spigot end of the pipe, is driven well home into the base of the socket, care being taken that not more than a quarter of the depth of the socket is taken up by each gasket. Portland cement mortar is then forced into the joint until the whole space round the spigot between it and the socket is quite full. The joint is then finished off with a neatly splayed fillet of pure cement. Each joint should be carefully examined in the inside of the pipe, and any cement that has oozed through should be carefully smoothed off.

When there is much water in a sewer trench, it is a good plan to protect the pipe joint by means of a piece of cloth tied around each joint, or preferably to use a good patent joint.

After all the joints have been carefully made and before the trench is filled in, what are known as the "disk test" and the

"water test" should be applied to each length of pipes between manhole and manhole.

The former test consists in passing a cylinder of wood. About half an inch less in diameter than the pipe, through the whole length of the sewer to ensure its being clear of rubbish.

The latter test consists of closing the lower end of the pipe and filling it entirely with water, until a head of at least 12 inches is obtained in the upper manhole. If there is no fall in the level of the water after two hours, it may be taken that the joints have been well made and are water-tight, and the particular length of the pipes tested may be passed. This is an important test, which should never be omitted and should always be made while the pipes are exposed.

It is not practically possible to lay pipe sewers so as to have complete immunity from leakage. There is usually in waterlogged ground a certain sweating from the cement joints. Also the junctions between the house connection and the pipe sewer are very liable to leakage unless made with great care, and the house connections themselves are a frequent source of leakage. The Author has generally laid down for pipe sewers that the leakage shall not exceed 2 gallons per mile per minute, including the manholes.

Plate 3 gives the details of circular manholes on pipe sewers, which are constructed on lines of sewers for the purpose of inspection and cleansing: they should not be more than 200 feet apart, and the sewer should always be laid straight between manhole and manhole so as to facilitate inspection and cleansing and to ensure there being no gaps or spaces in the joints of the pipes.

Manholes are generally constructed of brickwork set in cement and, though usually rectangular or circular, may be of any shape. The thickness of the brickwork will vary, according to depth, from 18 to 9 inches. A manhole should usually be founded on a 12-inch layer of cement concrete. In the case of rock, this may be reduced to 6 inches. The circular shape has found most favour

in Bombay, since, on the removal of the cover, the inspection of the whole of the floor can be at once made. Circular manholes will vary in their vertical section according to the depth and the class of soil in which they are constructed, the dome shaped sections being recommended for depths up to 5 feet 6 inches and the conical shape for greater depths. The top and bottom of manholes are the same in size for all depths. The sides of a conical shaped manhole at a depth less than 5 feet 6 inches would so slope as to be dangerous to the structure, and accordingly for manholes of less than that depth a dome shape is recommended.

It is desirable to cover manholes, both inside and outside, with a half-inch plastering of cement and sand in the proportion of one to one, so as to keep them absolutely water-tight. Step irons should always be fixed inside manholes during their construction, when the depth exceeds 4 feet. The flooring of manholes should be made of cement concrete, having half-round channels formed in it, at the same gradient as the pipe, and with vertical sides of the same height as the pipe, such flooring and channels being finished off with a rendering of cement plaster. It is desirable in all manholes to place an indicator stone, with the number cut into it, near the top and under the cast iron frame. In a dome shaped manhole, it is not possible to place a stone under the frame so as to be visible, and it should therefore be placed in the floor as shewn in Plate 3. Around the mouth of the manhole, a fillet of cement and sand (1 to 1) should be placed for the reception of the cast iron frame, which should be so bedded on the masonry of the manhole that the top may be slightly above the original surface of the road, this level being designed to prevent the entrance into the manhole of storm-water.

In certain places it may be found either inconvenient or too expensive to build manholes of brick; in such places concrete manholes are recommended, but they should only be built where bricks are very costly or poor in quality.

Circular concrete manholes with a uniform batter from top to bottom are undesirable, as requiring varying forms to build them on for different depths; and it is therefore usual for concrete manholes to be built either canister shape, square, or rectangular, but such square manholes are more liable to sweat than brickwork.

As to thickness of walls, the depth of manholes and quality of concrete will govern that, and no fixed rule can be laid down.

Plate 4 shews two patterns of manholes covers and frames in use in the Bombay Sewerage Works. Both are good types, but that shewn in Fig. 2 is the newer and probably the better. The weight of frame and cover should not be less than $6\frac{1}{2}$ cwt. It will be noticed that the cover fits into a slot in the frame, which ordinarily is soon filled with sand from the road surface, and becomes not only a water-tight but a fairly air-tight joint.

It is important, in districts which are liable to be flooded and which are drained on the separate system, that the manhole covers on the sewers should be water-tight. The type of cover shewn in Fig. 2 was recently experimented upon by constructing a water-tight wall round the frame and filling up the space with 12 inches of water, the cover thus forming the bottom of a cylindrical vessel; and it was found that with ordinary road detritus filling up the space between the cover and the frame, the whole was to all intents and purposes water-tight.

In cases where branch pipe sewers enter the manholes on main pipe sewers at a higher level than the main sewer, a drop pipe should be used as shewn in Fig. 24. As will be seen, the branch pipe sewer is brought down at an angle and finished with a bend discharging into the manhole at the main pipe sewer level, while an overflow and inspection pipe is provided by continuing the branch sewer pipe straight into the manhole and closing it with a metal flap valve. This arrangement avoids the splashing of sewage in a manhole—a proceeding conducive to the generation of sewer gas.

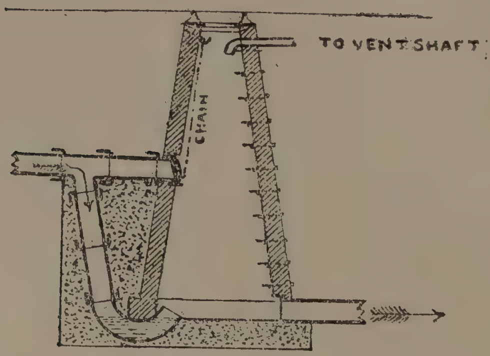


FIG. 24.

Flushing Tanks.—The provision of flushing tanks is very desirable in all sewerage schemes. The number and size of these tanks must depend to some extent on the gradients of pipe sewers and the class of sewage, but in general it is advisable to fix one at the head of each section. Plate 5 shews the type of flushing tank commonly in use in the Bombay sewerage system. The tank is constructed of brickwork in cement or hydraulic mortar, and rendered with a half-inch coating of cement and sand (1 to 1) covered with stone slabs 6 inches in thickness, with the manhole frame and cover of the type before described fixed over the siphon They are usually constructed to contain from 100 to 600 gallons, according to the length and diameter of the sewer they flush. The flushing siphon is fixed in a chamber in the centre of the tank, the floor sloping both ways towards it. The lower end of the siphon dips into the water in the chamber and forms a trap. The water rises on the inside of the tank until it reaches the lip or adjutage, and, dropping over, expels a quantity of air, which continues until a partial vacuum is formed and siphonic action is set up, when the whole of the contents of the flushing tank is discharged. Each tank is fitted with a tell-tale, connected to a float, which registers each flush. The water-supply pipe should be provided with a reserve ball-valve.

The connection between a flushing tank and a manhole should be constructed in the manner shewn in Plate 6. A 6-inch cast iron discharge pipe from the flushing tank is built into the wall of the manhole and carried down by means of a bend so as to terminate two inches below the top of the channel of the manhole. This bend is fixed to the wall by means of a wrought iron strap, the details of which are given in the Plate. The floor of the manhole is inverted so as to carry the whole flush directly towards the outlet sewer.

Flushing Disks.—Messrs. Mather and Platt have introduced a flushing disk, which effects the holding up and discharging of sewage automatically and may very likely obviate the necessity of a permanent staff.

As an alternative to the disk valve, the flap valve shewn in Fig. 1 on Plate 7 is often used. It is fixed on the inlet sewer of a manhole and provided with a chain for opening and a strut for keeping the surfaces water-tight when closed. The flap is made, of metal hung on hinges set with lead or cement in a stoneware block which is built into the brickwork of the manhole. A ring should be provided on the chain to fasten on to a hook just below the manhole cover, so that the flap can be kept wide open when not in use.

Flushing Doors.—Flushing doors, similar to tidal flaps as described in the catalogues of various manufacturers, are an undoubted aid to flushing large sewers, as by these means a great quantity of pure water, which would otherwise be necessary, is dispensed with. Broadly speaking, a flushing door is a hinged iron flap placed in a manhole on the inlet side of the sewer. This can be securely closed, when required, so as to head up the sewage on the upper length of the sewer to any required extent. On opening the door, which should be done as rapidly as possible, the whole of the pent up sewage rushes forward at a greatly increased velocity to that which would be obtained in the ordinary way, scouring before it solids and other matter, which

would otherwise tend to form a deposit on the invert of the sewer.

Large flushing doors, such as are used in the main ovoid sewers in Bombay, are provided with a hinged strut to keep them securely in their place when closed, and to this strut is attached a chain, by means of which the door can be raised to a horizontal position when required.

A reference to Plate 8 will shew the door in its lowest position and the hinged strut preventing it from opening. To release the door a chain is provided which is fixed to the ring (A) on the strut. In the larger sized doors, this is connected in a small chamber immediately below road level to a winding apparatus or to the lifting gear, as it is found impracticable to lift these doors by a direct pull. The joint (B) on the strut, being lifted, takes the position shewn by the dotted lines, and easily drops back into its proper place on the chain being released. These flushing doors have been found most useful in Bombay, where the accumulation of silt in the sewers is considerable.

A somewhat similar method of flushing can also be used for pipe sewers, but the valve, which is preferably of a disk type, is in this case placed on the outlet from the manhole, and an overflow from the manhole (about 3 feet above the invert) is usually provided, discharging into the outlet sewer. The object of this overflow is to guard against the risk of the door being closed and accidently forgotten, with the result that the sewage would force its way out of the lowest manhole cover. These small valves are inexpensive and undoubtedly useful, and might advantageously be placed a short distance from the head of branch sewers, simply leaving a sufficient length of sewer between the valve and the head manhole in which to store up enough sewage to create a satisfactory flush. In good gradients these valves should be built into the manholes at intervals of 1,000 feet, but if the gradient is flat, then they should be placed at intervals of 500 feet.

It must be borne in mind, when considering the adoption of appliances of this kind, that an efficient and separate permanent staff is necessary to work them.

Catchpits.—These have been found necessary in the Bombay sewerage system, both for ovoid and pipe sewers, and are recommended for general use in India. The principal reason for their adoption is on account of the large amount of mineral matter, in the shape of sand, ashes, and road detritus, which, as before stated, finds its way into the sewers through the branch drains from every point. The catchpits as constructed in Bombay are shewn in Plates 9 and 10. They have successfully stood the test of time, and year by year their number is being increased as the sewerage system is extended. In the districts sewered on the Pneumatic System of drainage, they are not required, because there it is possible to adopt steeper gradients and thus to decrease the possibility of the deposit of solid matter. The construction of catchpits on ovoid sewers should be wholly in cement brickwork or masonry. They should be fitted at both ends with penstocks, as shewn in Plate 9 and should slope towards the centre so as to facilitate cleansing. Each catchpit must be constructed with a cast iron by-pass, which is put into use only during the time of the cleaning of main chamber. With catchpits on pipe sewers (Plate 10), the by-pass is done away with by having two chambers, both of which are ordinarily brought into use, except when the catchpit is being cleaned. Instead of a penstock, these catchpits are fitted with sluice valves, their size being governed by the size of the respective pipe sewers. Care should be taken in cleaning out these catchpits, for, when the silt is disturbed, they are apt to dangerously fill up with gas. There is no question as to the utility of these catchpits, at any rate in Bombay, as both small and large regularly fill with silt and require to be cleaned out at least once a month, and any scheme for the disposal of sewage with similar characteristics to that of Bombay would not be complete without catchpits.

Ventilation.—One of the most important questions connected with sewerage schemes, and one that has exercised the minds of Sanitary Engineers for many years, is the efficient ventilation of sewers. It is not alone sufficient to merely ventilate a sewer and keep it reasonably free of poisonous gases, but it is imperative that the ventilation should be so carried out as to cause neither nuisance nor injury to the public, which can only be avoided by great care and judgment.

Sewer gas has been described in Moore's *Sanitary Engineering* as a "Fetid Organic Vapour"—a very apt description of it. Chemical analysis of the air in sewers shews it to generally consist of marsh gas (CH_4), Carbon Dioxide (CO_2), Ammonia (NH_3), Nitrogen (N), greater or less quantities of Sulphuretted Hydrogen (H_2S) according to temperature, and Carburetted Hydrogen ($C_2 H_4$).

Carbon Dioxide, or choke damp as it is also called, is the result of decomposition, and when inhaled in any quantity causes instantaneous prostration, often followed by death.

The presence of Nitrogen in sewers is due to the denitrifying of the organic matter in the sewage, which is the first stage of the bacterial work. Carburetted Hydrogen in sewers is often due to the leakage of gas pipes, but more often in this country to the decomposition of vegetable matter. It has a faint smell, something like burnt hay. In the Bombay sewers a large quantity of this gas accumulates. It is very explosive when mixed with atmospheric air, and for this reason no naked lights should ever be used in sewers until after they have been fully tested as hereinafter described.

Marsh gas, which is analogous to Carburetted Hydrogen, is the result of decomposition of vegetable matter and burns easily with a blue flame when ignited.

Sulphuretted Hydrogen—a gas nearly always present in sewers—is also a product of putrefaction; it has a very offensive smell and is heavier than atmospheric air; it is one of the most poisonous of all gases and has been responsible for the deaths of numerous

workmen in sewers from time to time; it mixes freely with fresh air and becomes then comparatively harmless.

The ammonia present in sewer air is the result of bacterial action.

The mean temperature of the sewage in Bombay is about 76·5°, while the mean temperature of the air as registered at the Meteorological Observatory, Colaba, on the average of the observations of 56 years, is 79·60°. It is obvious that at a temperature of 76·5° in the sewers, putrefaction and therefore the discharge of foul gases from the sewers will be great, and the fact that the temperature of the air is greater than that of the sewers is not in favour of successful ventilation.

Fresh sewage, however offensive it may be, is virtually harmless, but in its transit through sewers it becomes progressively noxious and dangerous.

Barometric changes affect the amount of foul air present in sewers. The lowering of the barometric pressure leads to the escape of gases in the sewage and favours decomposition and putrefaction, while an increase of barometric pressure enables the sewer air to carry a larger amount of vapour and therefore for the sewage to retain a larger amount of these gases, which are due to decomposition.

Increase of temperature of the liquid tends to expand the air held in the sewage, and consequently a quantity of the offensive gases is driven off under some pressure.

Temperature and barometric pressure are therefore very potent agents in connection with ventilation.

Steam, hot water, and waste chemical products are all active agents in setting up decomposition in sewers and thereby freeing gas. Sodawater manufacturers are especially culprits in this way, and the discharge into a sewer of waste water from a sodawater manufactory highly charged with carbonic acid gas has in Bombay prevented any access to the sewer in the immediate neighbourhood for days together.

Experiments made by the late Mr. Santo Crimp tend to show that the direction and force of wind are great factors in ventilation, and he has stated that ordinary ventilating shafts often act as inlets or outlets according to the condition of wind for the time being.

That sewer gas has the power of predisposing the human body to disease is, no doubt, true, though there is no direct evidence to shew that it is the immediate cause of zymotic disease, but it is quite conceivable that it is an indirect one. On the other hand, it is a curious fact that the health of employees at Sewage Pumping Stations compares very favourably with that of people living elsewhere, and this is borne out in Bombay. New-comers, however, often suffer in divers ways, which suggests that the poisons—if poisons they be—which surround such stations are such as people can soon become immune to.

Some years ago, Mr. J. Parry Laws, of the London County Council, made some interesting investigations into the air in sewers, and proved that the micro-organisms found in sewer air were related to those in the external air; that they bore no relation to those in the sewage itself; and that, however full the sewage might be of disease germs, they would not pass into the air of the sewer, except possibly under conditions of great splashing. But in a later report he says that "although one is led almost irresistibly to the conclusion that the organisms found in the sewer air do not probably constitute any source of danger, it is impossible to ignore the evidence, though it be only circumstantial, that sewer air has had causal relation to zymotic diseases."

Dr. Louis Parkes, M.D., D.Ph., in the *Journal of the Royal Sanitary Institution* of April, 1895, is inclined to rather dissent from the opinions of Mr. Parry Laws, for he says that "it is clearly impossible that Mr. Laws' experiments could take account of all the varied conditions to which sewage may be subject in sewers. We know that at times steam, and large quantities of waste water at a high temperature may be injected into sewers from

manufactories. Various chemical waste products also, acid or alkaline, occasionally find their way into sewers, and may then set up chemical decomposition in the sewage, and tributary sewers frequently discharge their contents into main sewers so as to cause much splashing and agitation of the sewage. The local effects produced by these various conditions—and by others which will suggest themselves to the minds of those familiar with sewers—must be investigated at length before it is possible to assert thatat no times and on no occasions are micro-organisms characteristic of sewage to be found in the air of sewers."

Many other notable Chemists and Medical Scientists have claimed that sewer air is incapable of disseminating the germs of disease; but it is almost certain that persons living in houses to which sewer air has access are more liable to zymotic diseases than those who live in a pure atmosphere. It is therefore of the utmost importance to carefully provide vent shafts for sewers and to ventilate house connections.

The term "ventilation" is usually employed to mean both the venting and the ventilation of sewers, *i.e.*, the letting of air out of and into the sewers; but the two terms should be differentiated as each refers to distinct operations. Sewers should be vented and house drains ventilated.

For this reason all manholes on sewers should be made air-tight and the vent shafts, as they naturally do, may be allowed to act as inlets and outlets alternately, in accordance with the meteorological conditions prevailing at the time, and as the depth of liquid in the sewer for the time being falls and rises.

Sewers laid at sharp gradients require more care in venting than those on flat gradients, because the gas naturally finds its way to the highest point of the sewerage system, sewer gas being generally lighter than atmospheric air. This, however, may not always be the case, as with quick velocities the gas is sometimes carried along with the sewage.

Vent shafts should be as few as possible consistent with safety, the number being governed by the varying flow of sewage and the size of the sewers. Care should be taken to provide sufficient to prevent the pressure of the gas forcing the traps on the house connections, and they should not be less than 6 inches in diameter. The distance between vent shaft and vent shaft should, as a general rule, not exceed 400 feet. This distance has been found in Bombay to be satisfactory, provided no special conditions prevail, such as the discharge of hot water or chemicals into the sewer. Under the latter conditions the shafts should be as close together as circumstances may require.

The selection of the positions for vent shafts require careful consideration, and no hard and fast rule can be laid down in regard to them. They should, however, in all cases be as far removed from dwellings as possible; but if the local circumstances oblige their erection near dwellings, they should be carried up well above the roof of the highest house within a radius of 200 feet. Sewer gas will travel long distances in the direction of the prevailing wind and in a city like Bombay, where houses are, for the most part, open night and day, the greatest care should be exercised in fixing vent shafts. These shafts, when fixed against houses, are for the most part made of iron, which, being a good conductor of heat, has the effect of creating a draught from the sewer. Therefore, if possible, a vent shaft should be fixed where the sun can shine on it for as many hours as possible.

The greatest care should be taken to see that all the joints of a vent shaft are most carefully made, so as to prevent leaks.

The usefulness of vent shafts depends on the difference of the pressures of air at the outlet and the inlet of the shaft, less the loss caused by frictional resistance.

In designing a vent shaft, it should always be remembered that the frictional resistance of the shaft modifies the current, the amount being in direct proportion to the length and inversely to the diameter or area of the shaft. Vent-shafts should, therefore,

err on the side of being too large rather than too small, and should be of the same size from top to bottom. The nearer the sectional area of the vent shafts is to that of the average air space of the sewer it vents, the more efficient will it be.

In any system of sewer ventilation, simplicity and independence of mechanical aid are desirable. Natural ventilation should be made use of as far as possible, and gases on leaving the outlet of a vent shaft should be exposed to as much dilution with fresh air as possible.

It must always be kept in view that just as much fresh air as is admitted into the sewers must leave those sewers again as foul air.

The question of sewer ventilation is a very difficult one, and the last word has not been spoken in regard to it.

Some authorities now hold that sewer air has a greater density than atmospheric air, and does not rise, as is generally believed but is forced out of the sewers by the rise of the sewage or by the formation and pressure of the putrefactive gases in the sewer.

Plate 11 gives a drawing of an ordinary metal vent shaft as used in Bombay. It is rectangular in section and is $7\frac{1}{2}$ inches by 4 inches. A masonry shaft, or sometimes an iron column, is used in places where there is no building to which a metal shaft can be fixed.

Plate 12 gives a drawing of an ordinary metal vent shaft, which has answered admirably in Bombay and other places. It can with safety be erected to a height of 60 feet without iron stays; and, being of cast iron, it is constructed in several pieces.

The practice of leaving openings or grids in manhole covers for ventilating purposes has found many supporters, and even to-day some Sanitary Engineers consider it suitable means of ventilation; but Engineers who have had much experience in the matter of ventilation, know that the surface grid ventilation must under all conditions be a fruitful source of nuisance. In some schemes with which the Author was connected in England, the force of public

opinion was so great that the surface grids which were fixed whe the sewerage was carried out had all to be closed within a shor time. It is quite certain that with the high temperature that prevails in the East, no such class of ventilation would be tolerated for a moment. The greatest care has to be exercised in Bombay to keep manholes absolutely air-tight, and a special form of manhole cover, referred to elsewhere, is used for this purpose.

The question of the ventilation of sewers was a matter that was carefully gone into by a departmental committee of the Local Government Board, published in 1912, when that committee sat to enquire into and report on the use of intercepting traps in house drainage.

In that report the case of Bristol is cited as being a large city with no ventilation of any kind, and yet in spite of that the death rate of Bristol is nearly as low as that of any large city in the United Kingdom, and the average death rate from typhoid is even lower. The Medical Officer of Health for the City states that he has been unable to establish any relationship between ill health, or any definite disease, and drainage defects in Bristol.

Another instance is that of East Grinstead, a small town f 7,000 inhabitants in Sussex, England. No ventilation of the sewers is provided outside the house pipes, and there again the Medical Officer states that he has been unable to trace any ill effects on the health of the town due to the system of drainage. But because towns in a cold climate, without a system of ventilation remain healthy it is not to be imagined that the same result would occur in an eastern climate where sewage so soon putrifies.

The Author cites the two above instances to show that the question of ventilation is largely unsettled, and that there are many advocates for and against.

There are various kinds of mechanical ventilation, a slight description of some examples of which may be useful.

The extraction and destruction of sewer air by a gas jet is a form of ventilation which has been used in many places in the

British Isles. One of the principal forms of this is known as J. E. Webb's Patent Sewer Gas Extractor and Destructor Lamp. By this system it is claimed that the sewer air is drawn out of the sewers and subjected to a temperature of 600° F., and that all disease germs and noxious gases are absolutely destroyed. It is stated that the lamp costing some £20 will effectively ventilate one mile of an average sized sewer, the extracting capacity being 2,500 cubic feet of sewer air per hour. These lamps, which are in the form of ordinary street lamps, it is said, can be used equally well with incandescent burners. The economy of using this system is obviously dependent on the price of gas, and it is possible that in the East, where only a few towns have the luxury of gas, the cost of the commodity will be too great to allow of it being used economically.

In connection with the Shone Pneumatic System of Drainage the exhaust air having been in connection with the sewage, while still keeping a certain amount of its pressure is disposed of as shown in Plate 1.

This Plate shews how the connections are made between an ejector and the sewers, and an ejector and the sealed sewage or rising main. There are two pipes rising from the top of the ejector, one of these being the air main, supplied direct from the engine house, and the other the exhaust pipe through which the compressed air, after having done its work by forcing the sewage through the outlet of the ejector, is allowed to escape. This exhaust air passes through a layer of coarse gravel before it finds its way out of the outlet shaft. This is an arrangement much advocated to dry the exhaust air before being finally discharged, and is not intended in any way to disinfect the air, for which some material, such as charcoal, would be necessary. The shaft nearest the ejector is the ventilator, into which the exhaust pipe discharges, each ejector chamber being supplied with a shaft of this description, generally about 50 feet high. This constitutes the only ventilation the Pneumatic system has. The shaft shewn on the

Plate furthest away from the ejector is an air inlet shaft, and one of these is usually placed at the head of each length of a gravitating pipe sewer. The object of this shaft is to supply fresh air to the pipe sewers, replacing the foul air which is drawn out of them by the action of the exhaust air from the ejector. The sliding openings in the heads of these shafts require to be carefully adjusted, those nearest the ejector chamber being partially opened, and those further away being fully opened so as to obtain a regular distribution of fresh air.

The ventilating shafts work very efficiently on this system, the exhaust air discharged through a nozzle into the shaft inducing a current, and thus drawing a quantity of foul air from the gravitating sewers. But this foul sewer air is very apt to be discharged from the ventilating shafts in puffs and carried by the prevailing wind, long distances, into neighbouring houses. This has been the experience in Bombay, and a serious nuisance has at times resulted. There are many reasons which prevent ventilating shafts being raised to any great height, and in the neighbourhood of dwellings it is consequently desirable to treat the gas in some way before it leaves the shaft.

In 1906 Mr. Shone patented another system of ventilation, which he calls the "20th Century System of Ventilation," and it will not be out of place here to give a brief description of it. The general principle on which the system is based is the creation of a partial vacuum in sewers and the admission of controlled volumes of atmospheric air through patent valves on the house connections, all other inlets to the sewers being either stopped or trapped. The partial vacuum, which is equal to about half an inch of water, is produced by means of an exhauster fan driven by some motive power such as steam, electricity, or compressed air. The air removed from the sections of sewers thus dealt with is discharged through one vent shaft fixed in connection with the fan.

It is evident that if the proportion of the atmospheric air is very large as compared with sewer gas, the resultant mixture

can be safely discharged into the atmosphere without causing any nuisance.

For this scheme to be successful, it must have the sewers or the system of sewers absolutely air-tight, and any leaky joint or manhole cover would seriously militate against the successful working of the whole system.

Plate No.13 shews the system in detail and the position of the fan.

The system has been installed among other places at the village of Darley Abbey, at Leicester and at Manchester.

At Darley Abbey the system is a complete one, that is to say, the whole of the sewers of the village are ventilated by Mr. Shone's system. The present number of houses in Darley Abbey is 200 and the estimated population is from 1,000 to 1,200. The water supply is equal to 15 gallons per head, but the sewers are designed to take away double that quantity. A 15-inch Sirocco Fan, capable of making 1,500 revolutions and delivering 500 cubic feet of air per minute up the ventilating shaft, is fixed in a convenient position at the lowest part of the drainage system, so that the tendency of the air to move downwards in the direction of the flow of sewage may co-operate slightly with the work of the fan. Mr. Shone considers that if a volume of fresh air, equal to 1-10th of a cubic foot per minute per inhabitant, is sucked into the system through the inlet valves, it will be able to dilute the gases of any sewage sufficiently to permit of their being discharged into the open air with impunity. The volume of air required to ventilate the sewerage system at Darley Abbey on the basis of 1-10th of a cubic foot per minute per inhabitant would only amount to 120 cubic feet; but looking to the fact that an allowance has to be made for leaky manholes, etc., the fan has been designed to deal with 500 cubic feet per minute. This has proved to be an ample allowance, and the installation has been working satisfactorily for several years. Plate No. 14 is a drawing of a regulated air inlet plug, which is considered by the Author to be a satisfactory arrangement.

At Manchester, the authorities are said to be quite satisfied with the efficiency of the system. As regards Leicester, the Borough Engineer, Mr. John Mawbey, M.Inst.C.E., has published an account of his experience of it at that place. He states that the area under the influence of the system is $2\frac{1}{2}$ acres and comprises portions of the more modern part of the borough. The total length of the sewers ventilated is about 900 feet. The sewers are laid at an average depth of 10 feet, being principally 12 inches in diameter, discharging into a 3 feet by 2 feet ovoid sewer. The house drains connected with these sewers comprise a length of about 1,750 feet, being mostly 6 inches in diameter.

There are no intercepting traps on the pipe drains. Of the 80 houses connected to the system, 27 are provided with ordinary ventilating pipes. At the lower end of the system a chamber is provided containing a 15-inch Sirocco Fan, driven by an electro-motor working at 700 revolutions per minute. One end of the chamber containing the fan is connected to a circular steel ventilating shaft, 40 feet high. The fan is connected to this shaft by a zinc pipe, tapering in size from 7 inches square to 9 inches in diameter. The working expenses of the system are practically confined to the cost of the electric current consumed in driving the motor. The repairs and maintenance are very small. The first experiment extended over a period of five consecutive days. The velocity of the air discharged through the extraction shaft and of the air entering at each inlet was registered by an anemometer. Once during each of the five days a 10 minutes' test was taken at each of the 27 inlets. The average result of these tests was that 275·10 cubic feet of air per minute were extracted through the extraction shaft, at an average velocity of 1,266 feet per minute, and a total of 31·17 cubic feet of air per minute was admitted to the 27 inlets on the private ventilating pipe at an average velocity of 29·3 feet per minute. The inlets in the private ventilating pipes varied in diameter from 5-16ths of an inch to one inch, and the total area of the 27 inlet pipes was equal to 10·278 square inches.

There is a great discrepancy between the total volume entering the inlets, and the volume leaving the extracting shaft, due doubtless to the fact that the volume of air entering these inlets is too small to be registered, and also that some of the air is drawn in through the manhole and lamp hole covers.

In the second test that was made, the size of the extraction shaft was increased from 6 inches to 9 inches, with the result that a largely increased amount of air was extracted. The result of the experiment satisfied Mr. Mawbey that the system was both practical and efficient, and one on which reliance could be placed through out all seasons of the year. Five sets of air analyses were made during the experiment, and they shewed that the external air contained on an average 3·55 parts of carbonic anhydride per 10,000 parts of air; that the air in the manholes at different parts of the system contained on an average 15·10 parts of carbonic anhydride; and that the air as discharged at the extraction shaft contained 13·14 parts. Since the above was written the Author is informed the system has continued to give satisfaction.

As stated earlier, the last word in regard to ventilation has not yet been said. It is a fact which the Author considers should be kept well in mind by Sanitary Engineers, that any expensive method of mechanical ventilation is likely to add very seriously to the cost of a sewerage system, which often constitutes a severe burden not only on the rates but also on the rate payers. A considerable amount of the work is doubtless carried out at public expense; but some portion, and that by no means insignificant falls on the house-owners themselves. Any kind of mechanical ventilation will, however, assuredly add more or less to the cost of a scheme. At present, even in the British Isles, where many experiments have been carried out in regard to ventilation, there is a great variety of opinion as to which is the most suitable method.

The Author has given much thought to the subject, and is of opinion that, so far as our present knowledge goes, the venting of

sewers should be attained by means of vent shafts of suitable size placed at regular intervals, the manhole covers of the sewers being made practically air-tight.

Removal of Obstructions in Sewers.—In India, all sewers are very liable to obstruction and chokes. The universal habit of cleansing cooking utensils with sand and the frequent use of broken tiles and road metal in latrines are the principal causes. In Bombay, the usual method of keeping the ovoid sewer clear of deposit or silt is to draw a shield or scraper through the sewer by means of a winch and chain. This shield or scraper is made of wood in two patterns, one with the bottom part cut off and the other with the top cut away about a third of the distance down : both are constructed of the same shape as the sewer, with wheels both at the bottom and the sides, and are of a size to leave about 1½ inch play on each side, to give greater facility in moving. The shield or scraper is dragged through the sewer from manhole to manhole, the sewage finding its way with increased velocity, either over or under the scraper, and thus softening the silt in front. The silt is pushed forward before the moving scraper into the nearest catchpit or goes on to the pumping station, where it is lifted with the sewage by the pumps. The scrapers are constructed so as to take to pieces, every part being bolted together when required for use. This is necessary, as the scrapers have to be put together in the sewers, and even then a specially large manhole is sometimes necessary to allow the larger part of the scraper being introduced into the sewer. The above method has been found to be the only means of moving the heavier particles of silt in the sewers. It has the disadvantage, however, of being destructive to the cement plastering of the sewer.

Where the silt is very hard, the scraper mounts on to the top of it instead of moving it forward, and this frequently happens where it is practically impossible to do any repairs. Plate 15 shews the apparatus in detail.

For pipe sewers usually a double disk, as shewn in Fig. 25, is used and dragged through them, the silt being removed by hand at the nearest manhole. This arrangement is probably as satisfactory a way of cleaning pipe sewers by hand as can be arranged and has been in use in Bombay for some years. At one time an attempt was made to clean pipe sewers by placing a round metal and hollow ball in the sewer, nearly the same size as the sewer and allowing the sewage to force the ball forward, but the attempt was not satisfactory, as the ball stuck hopelessly in the silt in the sewer and had to be dug out.

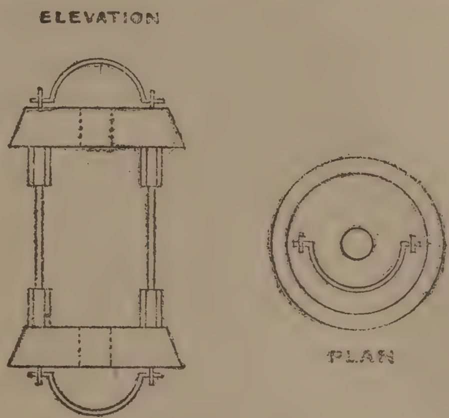


FIG. 25.

Rules to be observed in Cleaning Sewers.—The following precautions should be taken when men are required to enter and work in sewers and drains :—

When only two men are engaged in opening a manhole, it should be securely fenced round before the cover is removed, and the fencing should not be removed until the cover has been replaced. This precaution should be very carefully observed in order to prevent accidents to traffic, the liability for which may be brought home to the body responsible and heavy damages claimed.

If there are more than two men engaged the cover may be removed before the fence is erected, or the fence removed before the cover is replaced, provided that one man—not below the rank of a Foreman—be stationed at the open manhole, not to leave it so long as it is open. An open manhole, whether fenced or unfenced, should never be left without some one on guard to prevent

accidents, and the guard should not leave it so long as it remains open.

Workmen should on no account enter a manhole, except under the immediate orders and in the presence of the Chief Inspector. Inspector, or Sub-Inspector, or of a muccadum who has satisfied the Chief Inspector that he understands (and is competent and may be trusted to apply) the tests prescribed in these rules for deteımining the quality of air in a sewer.

Workmen should on no account go up a sewer beyond the manhole, except under the orders and in the presence of the Chief Inspector, Inspector, or Sub-Inspector.

The first duty of the person in charge of men entering a sewer, drain, or manhole is to see that he has supplied himself with the following appliances :—(*a*) chemical test papers; (*b*) lights; (*c*) bamboos; (*d*) windsails; (*e*) strong ropes and cords; (*f*) diver's air pump (or blast-fan); (*g*) air tubing; and (*h*) picks, *phaoras* (Indian shovels), pails, gamels, and whatever implements may be required for the actual work.

Not less than six manholes—at least, two in each direction, above and below—should be open when it is intended to enter either a sewer or a manhole.

The following sketch of a sewer with a series of six manholes in succession (A, B, C, D, E, & F) illustrates the system to be adopted :—

All the six manholes should be open for free ventilation for an hour or more before a man enters a sewer or a manhole. At B and also at E a windsail should be erected with the flaps kept extended towards the direction from which the wind blows. The work should commence either at C and proceed towards D or at D and proceed towards C. Assuming that the work begins at C, then

a diver's air pump or blast-fan, with a flexible air tube, should be set up at C and kept constantly at work. Before a man enters a manhole, the air pump or fan must be worked for five minutes and before going into a sewer beyond the manhole for ten minutes.

A competent man, according to the instructions contained in the above rules, should be placed in charge of the work, and he should satisfy himself by inspection at first, and from time to time afterwards that the sewer is not dangerous to work in.

It should not be overlooked that although near a manhole the air may be pure, yet further within the sewer it may be fatal to life ; and if a fatality occurs, it is as well to remember that a charge of culpable negligence may be brought, and very rightly, against an officer who orders a man to work in a sewer in which proper precautionary measures have not been taken.

Before the following tests are applied, the silt deposit at the bottom of the manhole should be first thoroughly stirred up with a rod or bamboo so as to agitate and dissipate the noxious gases, which would otherwise be a serious source of danger when disturbed by the workmen's feet.

Chemical papers for testing the presence of sulphuretted hydrogen gas should always be used.

If a paper, after five minutes' exposure in the sewer, turns a deep brown or black, the sewer is dangerous to work in, and further ventilation should be allowed and the test repeated before entrance is permitted.

If the paper test is satisfactory, a light may next be let down into the sewer by means of a cord running over the end of a staff, The light should be a naked light, that is to say, if placed inside a lantern, the door of the lantern should be open. This being a test not only for choke damp but also for combustible gas or fire damp, no one should stand near to or over the manhole while the test is being applied. If the light burns unnaturally or goes out, the men should not descend.

Even if the tests have been made and found satisfactory, no man should go down with a naked light, but only with a Davey Safety Lamp ; and one such lamp, if men are working in a covered part of the sewer, should always be kept 20 feet in advance of where the men are at work and they should be cautioned to observe that it burns properly. If it does not do so or goes out, the men should all return to the nearest manhole immediately and ascend to the surface.

No man should be allowed, on any pretext whatsoever, to be in a manhole or sewer with a naked light, and on no occasion should he smoke in the manhole or sewer or strike a match.

No man should enter a manhole when the sewage is above the crown of the arch of the sewer or the top of the pipe ; but if it be absolutely necessary to do so, the greatest care should be taken to watch the sewage, and in the event of its falling to within 2 inches above the crown of the arch or top of the pipe, the men should immediately come up and not re-enter the manhole until fifteen minutes after the sewage has fallen below the crown and fresh tests of the condition of the sewer have been applied.

Each man should be fastened by a stout rope passing under his armpits and with a knot against his spine : the rope should be kept from slipping down to the lower part of the body by means of short pieces of cord passing over the shoulders. The foremost man should have the end of the tube supplying fresh air from the fan always a little in advance of him, and should carry it himself if possible ; but if the latter be not found practicable, another man should be employed to carry the air tube.

In any case, one man should always be stationed at the bottom of the manhole to give an alarm and render assistance if required.

The men should be cautioned that if they feel any difficulty of breathing (or feel unwell in any respect), they should not remain in the sewer but come up immediately.

No man should be allowed to remain in a sewer more than half an hour at a time.

At least three men should be stationed on the surface of the manhole from which work is being carried on.

When the work has been completed from C to half the distance between C and D, the work should be begun from D and proceeded with towards C, similar arrangements and conditions being observed.

These instructions for executing the work between C and D apply to carrying out the work between any other two manholes, the windsails, air pump, or fan and other appliances being moved as required.

If an accident occurs, every person in the sewer, should be brought to the surface as rapidly as possible, and whilst they are being so brought out, crowding around the manhole should be prevented, because a crowd would check the escape of foul air or the entrance of fresh air.

If any person brought out of the sewer is insensible and medical attendance cannot be immediately obtained, some of the following should be adopted :—(*a*) Loosen all clothes about the body ; (*b*) dash water on the face, which should be towards the wind ; (*c*) lay the man flat on his face with one of his arms under his forehead, and (*d*) open his mouth, draw his tongue forward, and cleanse his mouth and nostrils with water, or (*e*) turn him on one side while supporting his head, and turn him back again on his face : if breathing does not commence, (*f*) turn him again gently on to one side and then on to his back ; (*g*) raise his head and shoulders ; (*h*) grasp both his arms just above his elbows and draw them gently but firmly upwards, and keep them in that position two seconds ; (*i*) lower his arms and press them gently against his sides ; and (*j*) continue to raise and lower his arms as described until breathing is restored or until the man is placed in charge of a doctor : if breathing be restored before the doctor arrives, (*k*) rub the man dry and wrap him in warm dry clothes ; (*l*) do everything possible to restore warmth and circulation ; and (*m*) as soon as the man can swallow, give him warm water or any kind of diluted spirits to drink.

CHAPTER IV.

Public Conveniences.

All Eastern towns of any size should be supplied with public conveniences in the shape of latrines and urinals, as otherwise road-side drains or odd corners would be made use of, and these in a tropical climate soon become offensive.

Generally, far too few conveniences are provided ; and that this is the case even in a well administered City like Bombay is evident from the use made of those that do exist, it being not uncommon to see persons awaiting their turn outside latrines and urinals. There is no doubt also that these conveniences serve the double purpose of preventing nuisances in the streets and of educating the lower classes to the necessity for sanitation and to the desirability of decency. It is almost incredible, but none the less true, that a large number of the poorer classes still require positive assistance in such an apparently obvious matter as the correct direction to face when using urinals. Two devices are commonly employed for this purpose : a small looking-glass fixed on the front wall of the latrine, about three feet from ground-level ; or the mark of an outspreadh and painted in red by means of a stencil- The vanity inherent in the very humblest human being makes certain that the glass will be faced with keen inquiry ; while religion ensures, among Hindus at least, that the back will not be turned to the sign of the hand. The imprint of the open hand has long been regarded by both Hindus and Mahomedans as a sign of plenty, and when placed on the wall of a building, it is supposed to invoke a blessing not only on such building itself but also on the inhabitants thereof. In consequence, many castes will not voluntarily turn their backs on so auspicious a sign.

The word "latrine" is used to describe a convenience on either a dry or a water-carriage system. For facilities in carriage, latrines are often constructed of corrugated iron with an angular iron framing: but it is not a desirable form of construction, particularly up-country, where during the hot season the iron gets so heated as to be quite unusable. The construction with wooden frames and brick nogging, though slightly more expensive, is decidedly better.

Dry Pattern Latrines.—The following are the descriptions of a few dry pattern latrines, for use in connection with cess-pools or sewerage systems, which have been widely adopted in India.

One of the simplest is probably that shewn on Plate 16, and known as the "Horbury Pattern Privy." This is constructed of corrugated iron sheeting fixed to an angle iron framing; the squatting plates are of cast iron and the sewage receptacles are ordinary iron buckets, generally well-tarred or dammered and easily removed on opening the flap door at the back. The flooring of such privies should be cemented or paved.

Another latrine which has found favour is the Donaldson pattern as shewn in Plate 17: these have been principally used in Bengal and Madras. It will be noticed from the design that the liquid—which is separated from the solids—is passed by means of a drain into a covered tank or reservoir, while the solids fall into a receptacle. The superstructure of the latrine is corrugated iron bolted to T and angle iron. All floors and surfaces are finished with Portland cement.

Plate 18 shews an ordinary type of privy much in use and constructed of wooden posts and brick masonry. In this privy the solid matter is retained in a cane basket about 15 inches in diameter and 12 inches high, the interstices of which allow fluids to pass out and flow over the cemented floor into a trap fixed on a pipe drain, which is connected to a cess-pool or a sewer according to circumstances. The cess-pool should be constructed underground, of brick masonry, plastered with cement, and of a capacity

below the level of the inlet pipe, equivalent to three cubic feet for every seat of the privy. It is covered with a cast iron or wooden cover and is ventilated by means of a 3-inch cast iron pipe, fixed in a convenient position and finished with a T head.

A basket can hardly be called a satisfactory receptacle, as in no possible way can it be kept thoroughly sanitary. The division of the solid matter from the fluid in this way is most undesirable because not only is the outside of the basket fouled, but also a large portion of the cemented space on which the basket is placed, and if this is not constantly flushed, it becomes a source of considerable nuisance ; while flushing causes large quantities of water heavily charged with night-soil to pass into cess-pools or drains not intended for such fluid. This is a frequent source of great nuisance.

Plate 19 gives a drawing of a range of the Crawford System Latrines, so called because they were introduced by the Bombay Municipality when Mr. Arthur Crawford was the Municipal Commissioner. In this class of latrines the solid and the fluid matters are collected in one bucket, the contents of which are removed by hand daily or more often if necessary. This is more sanitary than the basket system, and provided the buckets are regularly and frequently emptied, there is little objection to this method.

Plate 20 shews a range of Improved Dry-system Latrines which are similar to the Crawford System, but differ in so far that the receptacles for the solid and fluid matter are covered with iron perforated covers.

In both the above latrines, the sloping shoot, which is usually constructed of wrought-iron, requires to be daily cleaned and brushed by the attendant in charge of the latrines. The shoots as also the receptacles and their covers, should be well tarred or dammered from time to time. Tar is credited with considerable and lasting deodorising and antiseptic properties, and every application not only probably exerts these influences but covers up with an impervious skin any offensive matter that may have been

deposited. There can be no doubt that, for the special purposes for which it is recommended, it at present stands without a rival. Both latrines can be economically constructed on a masonry or concrete foundation with a cement flooring, the superstructure being of light angle iron standards with sides and roof of corrugated or sheet iron.

The size of a range of dry pattern latrines, *i.e.*, the number of seats it is to contain, is best arrived at by determining the population likely to use the latrines per day and allowing one seat for every twenty adults.

A convenient way of constructing a range of latrines is to place them back to back, those for males being on the one side and those for females on the other, with a 4-foot paved gully between for the removal of the basket or buckets and for cleaning purposes.

Latrines on Water-Carriage System.—Wherever possible latrines on the water-carriage system are to be preferred to those on the dry-system. Many forms of this class of latrine have been tried in Bombay with varying success, and of late years very great improvements have been made. It is only recently that manufacturers have constructed a porcelain or glazed stoneware pan of a shape agreeable to the natives of India. Previously cast-iron was used, and sometimes stone or concrete. This cast-iron pan was never successful, for it was difficult to keep clean, and as it could not possibly be made entirely smooth, it soon became coated with fœcal matter. The cast-iron pan is now obsolete, the porcelain or stoneware pan being largely used in both public and private water-carriage latrines.

The compartments of a latrine are usually built 2′—6″ × 3′—a size found to be sufficiently large. In one town in India a latrine was built with much larger compartments and attained an altogether unexpected degree of popularity, it being used as residential quarters.

Each compartment is usually provided with a three-gallon flushing-tank, fitted with a pull-off chain and a ball-cock ; but it

has been found that these chains were constantly being jerked off and stolen, and later a rod was substituted for the chain, but with no better success. Finally, automatic flush tanks were successfully substituted for these pull-off flushing tanks ; but this class of flushing tank, unless carefully watched, is very wasteful as regards consumption of water. It should be carefully adjusted to discharge four times daily, or as many more times as circumstances may show to be necessary. On the top of each range of compartments is placed a water-storage tank running the whole length of the latrine, fitted with a ball valve and containing about 500 gallons, so as to provide a storage of water for the latrines in case of an interrupted supply from the water main. This storage tank may not be necessary in all places, or if a constant supply in the mains can be depended upon.

Plate 21 gives a drawing of a water-carriage system latrine now in use in Bombay. In this a porcelain pan is substituted for the antiquated cast-iron form, and the inside of each compartment is lined to a height of three feet with white glazed tiles. Each latrine is fitted with a three-gallon automatic flushing tank, fixed on brackets at such a height as to be out of reach of interference. The soil pan is flushed from the front and also by means of a flushing rim, which surrounds the top of the pan. Foot-rests are also provided in the proper positions for the users to squat on. The special trap used in the old pattern latrine is here done away with, and the contents of the pan are discharged through an ordinary trap direct into the pipe drain.

Brass is especially esteemed by the natives of India, and it is not uncommon in these latrines to find brass handles and other fittings stolen. For that reason all fittings should be preferably of iron and bolted to their places.

In connection with an installation of latrines, it is desirable to provide a few small seats in the enclosed space for children. A properly paved and drained washing-place is also necessary, the water-supply pipe being fitted with an ordinary brass plug tap.

In public latrines on the above system, it is usual to fix the number of seats on the basis of one seat for every fifty adults who are likely to use the latrines per day.

Trough Pattern Latrines.—In places it will be found that trough pattern latrines have advantages over those on the water-carriage system just described. They are more suitable when required to accommodate large numbers of people, and for that reason are especially adapted for Mills and Factories.

There is practically no limit to the number of persons who may make use of a trough latrine daily, and there are no fittings which can be in any way tampered with. The structure can be made of corrugated iron or some such cheap material or masonry, latrines built of the latter material being naturally more lasting.

Plate 22 gives a drawing of a trough pattern latrine, which has given general satisfaction. In this latrine a depth of six inches of water always remains in the trough, which is generally constructed of a half 6-inch or 9-inch stoneware-pipe according to the number of seats. The trough is, automatically or at will, flushed from a 50-gallon flushing tank placed at its higher end. The form of the pan at its top is similar to that of the water-carriage latrine last described, with the lower half cut away, and is without any kind of trap. When this pattern of trough latrine was first tried, it was found that the users got splashed, and for this reason natives had a great objection to it. The trouble was, however, got over by hanging a small iron plate under the pan and just above the normal level of the water in the trough, so that, when the flushing tank discharged, this plate became completely covered and cleansed of any solid matter on it. This arrangement has removed the original objection.

Plate No. 23 shews an improved trough pattern latrine. Each compartment is provided with a glazed earthenware pan, the outlet of which is connected by a glazed stoneware pipe to the trough. The invert of the trough may be constructed of a four-inch glazed channel pipe, for any number of compartments

up to ten : above that number, a six-inch channel pipe should be used.

The invert of the trough should be level with a weir at the outlet and so adjusted as to retain $2\frac{1}{2}$ inches of water in the trough. Care should be taken to have the invert of the outlet pipe from the pans level with the water line in the trough. The trough is flushed by means of an automatic flushing cistern of the capacity of five gallons for any number of pans up to five ; and above that number the capacity of the flushing cistern should be increased at the rate of one gallon for each additional pan.

The working of this latrine is much assisted by the flow from a bathing platform or by a sink being drained into and through the trough. In some cases, such a flow has been found to be sufficient to efficiently flush the trough. Several of these latrines are in use in various mills in Bombay and have so far proved quite sanitary.

The Author considers that many of the objections to a trough latrine have been overcome by this improved pattern.

The "Delhi" Range Closets.—This design (Plate No. 24) is also very suitable for double ranges back to back, discharging nto a centre channel which runs in a passage to which access is obtained by means of a door at one end, so that the whole length of channel and connections can be inspected and cleaned periodically with a broom.

In each compartment is provided a cane colour or white enamelled impervious "Vulcanware" squatting plate, under which is a specially formed pan constructed in such a manner that no water surface is exposed, therefore splashing is entirely eliminated.

The pans are connected to the central channel by means of 90° easy bends of three quarter section open channelling. The space between these is filled up with a cement benching as in ordinary manholes.

The central collecting channel is provided with a flushing inlet at the high end. The lower end is provided with a weir so as to

retain a sufficient body of water, and the outlet is arranged to connect with a 6″ drain trap.

Access to the drain in case of stoppage is obtained through a 12″×12″ cast-iron manhole cover fixed over the inspection socket of the trap.

The partition walls and divisions are best made of marble or slate to economise space, but other materials can be used if preferred. When cheapness is a consideration the squatting plates can be omitted and the floor finished in cement.

With the automatic flush tank, Doulton's regulating stopcock is very suitable. After being regulated to allow the tank to discharge the desired number of times per day, it can be shut off and opened again without altering the regulation, thus saving a great waste of water at night or during other times when the fittings are not in use.

The Hindostan Native Closet Pan, by Messrs. Doulton & Co. has been specially designed to meet the habits of the Natives of India, where it is now in general use.

With a squatting plate of white marble and raised foot pads to indicate the position, flushing tank, pipe and white glazed tiling or marble lining to the walls of the recess or room where it is fixed, a native closet of this type is equal in appearance to the standard of excellence aimed at with high class fittings for Europeans.

For sanitary installations where cost is a consideration the marble squatting plates and tiled walls may be dispensed with, and the closet set in brick work with a squatting floor of cement floating, though a "Vulcanware" squatting plate is recommended where cost will allow of it.

A small drip sink and tap is provided for ablution purposes. Fig. No. 26 gives an illustration of this closet pan.

Plate 25 is a drawing of a Public Convenience which the Author erected in Cairo some three years ago. It is a trough pattern installation of latrines and has been used daily by some hundreds

of people since it was erected and has been an undoubted success.

The users of this latrine are principally the Mohamedans of the middle and lower classes, for whom it is most difficult to provide a completely satisfactory convenience.

Urinals.—As in latrines, so in urinals, great strides have been made in Bombay towards securing greater sanitary efficiency. One of the earliest urinals constructed in Bombay, and one that was in use for many years, is shewn in Plate 27. This urinal is for the most part constructed of iron and may be of any length and of various shapes. The compartments may be divided by wrought-iron partitions five feet in height. The pan of the urinal, which can be continuous from end to end, holds water which at the greatest depth is 6 inches. The users squat, as is the distinctive custom in India, on slightly raised iron-steps, and the urinal is flushed from an automatic over-head tank of a sufficient capacity at each flush to displace the whole of the standing water in the urinal.

Plate 28 shows a circular urinal on this system.

This type or urinal was never quite satisfactory, as, being almost entirely constructed of iron, it rusted rapidly ; while it was not possible to keep it in a sanitary condition, as it lent itself to misuse as a latrine, for which it was manifestly not suitable. These urinals were almost the first public urinals constructed in Bombay, but they have been nearly all replaced with the new pattern hereinafter referred to.

A form of urinal much used in Bombay is shewn in Plate 29. It is a trough pattern and was designed by the Author in conjunction with Colonel T. S. Weir, I.M.S., late Health Officer to the Bombay Corporation, and is known as the "Combined Constant Flushing Urinal." The trough is of white porcelain, and the front is lined with glazed tiles to a height of 3 feet 6 inches or as far as the copper flushing pipe. The urinal is flushed continuously from a tank placed on the top of the structure and extending nearly its

whole length. The size of the water-supply tank may be calculated on the basis of 50 gallons per division per day, so that, if the urinal has four divisions, the tank should hold 200 gallons. All parts of the trough and the front wall continually receive a small stream of water. The partition walls, which are marble slabs, are 2 feet 3 inches apart and 6 feet in height. The contents of the urinal discharge through a trap placed at the lower end and connected with the sewer. The name "Combined" was given to this urinal because of the great advantage of its being able to be used sanitarily either in a standing or squatting position, and is thus suitable for all races. From time to time, the trough and the front require to be cleaned with a dilute solution of sulphuric acid in order to remove stains, which after a while discolour the glazed surfaces. The urinal has been a success and is undoubtedly the most sanitary for general purposes yet constructed in Bombay. Many have been built in the City in various positions, and Plate 30 shews one placed in the angle of a wall.

The cost of such a urinal is somewhat greater than that of the old cast-iron pattern, but being a combined urinal, its advantages, greatly overweigh the slight extra expense.

Since the above was written the Author understands that Messrs. Doulton & Co. of Lambeth, London, have made some improvement in this combined constant flushing urinal.

It is stated that the improvement consists of reducing the overall depth of the fitting and that reduces expense in excavation and building, and also the cost of erection, and it is also stated that it now readily permits the use of the urinal on upper floors of buildings.

The use of continuous flushing for urinals has of late, to a large extent, been discontinued in England and periodic flushing substituted, because of the large amount of water used by the former; but in Eastern cities it is not advisable to economise water in a public convenience.

Underground Public Conveniences.—For the accommodation of the European population in Eastern cities Underground Public Conveniences such as those that exist in the large cities in England should be provided.

Up to about twenty-five years ago Public Conveniences were for the most part unsightly in design, a great danger and obstruction to traffic, and objectionable in many other respects. For these reasons the great centres of London such as Trafalgar Square, Piccadilly Circus, The Royal Exchange, etc., etc., were altogether without sanitary accommodation, and other parts of the city were very ill-supplied.

With the introduction of Underground Conveniences the objections mentioned, all disappeared; there were no visible buildings: instead of being an obstruction and danger to traffic the flat roofs of an underground convenience form simply Islands or Refuges which are found so essential to the safe crossing of London streets.

What are advantages in these respects in London would be equally advantages in some of the great cities in the East.

Plate No. 26 shows a particularly well arranged type of such conveniences and represents one constructed by Messrs. Doulton & Co., Limited, at Tooley St., London. The more important installations have accommodations for attendants to be constantly in charge, who for the most part take a pleasure in keeping the various apparatus clean and free from objectionable smells.

As the floor of an Underground Convenience is generally ten or eleven feet below the surface level, the question of being able to get a sewer connection sufficiently deep to drain the building is one that must have first attention. The nature of the soil must also be taken into account. If the soil is damp or springs are likely to be met with special care must be taken to protect the walls on the outside. In London a covering of Asphalt is generally applied to the vertical outside face of walls, and at the foot carried through the walls horizontally as a damp course. The

walls on the inside are faced with tiles or built in white glazed brick and all angles should be rounded. For ventilating purposes a fan is provided in the roof at a point where it is convenient to place a lamp column (with perforated base) directly over it and the vitiated air is driven out through the column. The fans are generally driven by electricity, but in some cases where a good water supply is available, they are "Water Driven" and the waste water, having driven the fan, is conducted into the Automatic Tank in connection with Urinals which it helps to flush.

The divisions to closets should be of marble and carried about 3″ clear of the floor on gun-metal feet. The woodwork in closet doors and stiles, mirror frames, etc., should be polished mahogany or oiled teak and the floors are generally laid in vitreous tiles. It is most essential that the conveniences be properly lighted, and for this reason the roofs are formed of Hyatt's pavement lights set on narrow stone kerbs and the whole carried on rolled steel joists. For lighting at night time there should be sufficient gas jets or electric lights to thoroughly illuminate each closet or lavatory apartment.

The steps leading down into the building should be of a hard stone or cement, and they are generally faced with Doultons' "Silicon" treads, which are practically everlasting, and stout brass hand rails should be provided on each side.

The Gates or Railings round staircases (which are really the only indication which can be seen of the presence of a lavatory) should be of wrought iron, and of as unassuming a design as will answer the purpose.

The selection of the Sanitary fittings is of the highest importance. They should be as far as possible of white glazed ware and quite impervious to moisture. The closets should be of a wash-down type with vulcanware tanks, or these may be supplied in cast-iron, but covered with porcelain enamel. The lavatories should be carried clear of the floor on cantilevers fixed in back walls, so that the space beneath the lavatories can be kept cleansed.

Plate 31 is also a useful design for both European and Natives of an underground public convenience. The depth of the structure, from the surface of the road to the floor, is 7 feet, it being also 1 foot 6 inches above the surface of the ground, but the underground depth can, if necessary, be greater, the level of the connecting sewer governing that point. The place is lighted by means of Hayward's Patent Glass Lights inserted in the roof. Steps are provided on one side for the entrance to and the exit from the structure. It contains two separate water-closets, one for Europeans and the other for Natives, and two hand-washing basins. Conveniently situated and next to the native water-closet is a washing-place fitted with a stand-pipe for obtaining water for ablutionary purposes. There are also provided six Combined Constant Flushing Urinals, three on each side, and a small ornamental drinking fountain is placed at the bottom of the stairs leading to and from the structure. The whole installation is complete both for Europeans and Natives, and should prove to be a very useful convenience in the business part of a large town. For the use of a water-closet a small charge could be levied to meet the wages of the attendant in charge. Some artificial method of ventilation is almost indispensable in an Eastern city for such a structure, and possibly the most economical would be by means of shafts topped with revolving cowls.

Plate 32 shews a useful and complete above-ground installation of public latrines, urinals, and washing places with a well-paved and drained enclosure. This and similar installations have been constructed and are in use in Bombay, and have all the necessary conveniences for both sexes. A partition divides the latrine into two parts for the different sexes, each side being supplied with its own washing-place. The latrines themselves are on the newest pattern as shewn in Plate 21.

Such an expensive class of latrine for use in all parts of the city is not recommended. In crowded and poor districts a trough pattern would be preferable, both on account of its lesser

cost and because of its greater sanitariness under careless usage.

Discretion is necessary in deciding on a pattern and size of public latrines, as certain classes of people will not use them under any circumstances, and certain classes are not yet sufficiently educated to use them properly.

Night-soil Depots.—In no Indian city has the introduction of water-closets in private houses yet become universal or even common. In Bombay, in a portion of the city, night-soil is still in parts removed by hand, either in tarred baskets or in carts into which the baskets are emptied, and taken to the nearest night-soil depot and discharged into a sewer.

Plate 33 shews a complete night-soil depot as now used in Bombay. The carts are backed across the set stone paving to the stops, until the discharge pipe is over the opening of the hopper. In the latter is fixed a grating, the bars of which are set close enough to prevent road metal and tiles from passing through them. The hopper discharges into a central tank, called the night-soil tank, with which is connected a masonry water tank, provided for flushing purposes. Running the whole length, and about 7 feet high above the night-soil tank, is fixed a water-supply pipe with two branches, one over each hopper for flushing it and its surroundings and for cleansing the cart if necessary. An ample supply of water is an absolute necessity in a night-soil depot of this description, for it is requisite to thoroughly dilute with water the contents of a night-soil cart before discharging them into the sewer. The final discharge from the night-soil tank into the sewer is arranged by opening, by means of a lever, a penstock fixed at the lower end of the tank.

Plate 34 shews a useful night-soil depot or Excreta Disposer of small size, designed by the Author several years ago, used exclusively for the emptying of baskets, and time and experience have proved the suitability of this appliance. It consists of a tank holding 50 gallons of water and divided into two compartments. The smaller compartment is fitted with an ordinary annular siphon,

the inner leg of which is trapped at the bottom and discharges into a branch drain in connection with the main sewer. Fixed on the top of the other compartment of the tank is a funnel of a size sufficient to take at its top a night-soil basket, which, being inverted, rests on a ledge on the inside of the funnel. An automatic three-gallon flush tank is connected to a flushing rim at the top of the funnel and serves to keep the funnel clear of night-soil. The basket, after being emptied through the funnel into the tank, is flushed by means of the upright water pipe, which shoots the water jet into the basket, thoroughly scouring its sides. The main tank is designed to dispose of three baskets of night-soil for every discharge of 50 gallons of water. Great care must be taken to see that the water pipe supplying the jet for cleansing the basket is so cut off from the water main as to prevent any possibility of it in any way becoming contaminated by night-soil. This should be preferably done by fixing a supplementary tank at such a height as to give the necessary pressure to the jet for cleaning purposes.

Washing Places.—Plate 35, Fig. 1, shews a design of a public washing-place. Such an installation should be paved with stone laid on concrete and jointed with cement. The paved space is usually divided by a central wall into two compartments, one side being reserved for males and the other for females. On each side of the wall is fixed a water-supply pipe with taps at convenient distances, an open channel being constructed at the bottom of the central wall for the discharge of the water, which drains at the lower end into a trap on a branch pipe drain connected with the nearest sewer : the paving on both sides is sloped towards this open channel. Around the whole of the outside of the paving should be fixed a line of curb stones, rising four inches above the pavement.

Cab Stands.—Plate 35, Fig. 2, shews the construction of a cab stand for a public street. The pavement in this case should be always of set stones. The stand should be 6 feet in width with

a slope of 2 inches from either side towards the centre. In the centre a cast-iron trough, $4\frac{1}{2}$ inches deep by 5 inches wide, is fixed running the whole length of the stand and having an opening at the top, one inch wide, to admit drainage. This metal trough should have a slope of 1 in 100 to one end and be there connected by a trap and a branch-pipe to the nearest sewer. Cab stands may be of any length to suit circumstances, but if greater length than about 200 feet, should be drained in sections.

Public Dhobi Ghat.—Plate 36 gives a drawing of a public Dhobi Ghat or place for washing clothes. Such a Dhobi Ghat can be made of a size to accommodate any number of dhobis or washermen. The central channel marked A in the section, is a general water tank fitted with a ball-cock to maintain the level of the water. B B are small tanks opposite each compartment, from which the dhobi obtains the necessary water for washing purposes and are filled by hand from the general water tank A. The stone on which the clothes are beaten is marked C, the covered shed being for the bhutti or boiler. The whole of the ghat is constructed of stone paving set on concrete and jointed with cement. A small charge per month is made for the use of each compartment. A Dhobi Ghat, as above described, is a desirable institution in every Indian town which has a water-supply and a drainage system, in order that all public places where clothes are washed may be brought under supervision and conducted with due regard to cleanliness and proper drainage. The filthy conditions under which clothes are generally washed, where no supervision is exercised and no suitable accommodation provided, cannot fail to be a fruitful source of danger to public health.

CHAPTER V

House Connections

The general principles of house connections adopted in Europe require considerable modification before they can be adapted to the peculiar conditions obtaining in most Eastern Cities. It is desirable, therefore, before describing the best system of house-drainage connections for Eastern Cities, to give a short description of a typical house and the manner in which the towns are often laid out: Large buildings abound, in which it is not unusual to find as many as twenty rooms on each floor, each occupied by a different tenant or tenants, and each furnished with a nahani or washing-place, known in some localities as a mori. In the bazars and other thickly populated parts, these houses are often separated only by narrow passages or gullies, which are provided both for drainage purposes and as a means of access to the privies, while the streets are generally narrow and badly paved; and to keep such localities healthy and sanitary is obviously no light task: refuse and rubbish, to save trouble, are generally thrown out of the nearest window, and the consequence of this practice, combined with the fact that the washing-place which is provided in nearly every room is by no means always confined to the purpose for which it is intended, is that the gullies between the houses soon get into a filthy condition and a large staff of scavengers has to be maintained by the Municipal authorities to clean and flush them.

The first method adopted for dealing with these gullies in Bombay was as follows :—A 6-inch stoneware pipe drain was laid in the gully and disconnected from the sewer in the street by means of a running siphon; each waste-water pipe discharged into a trap placed at the foot of it, and was connected to the 6-inch pipe drain by a 4-inch pipe; traps connected with the 6-inch pipe drain

were also provided for the privy sullage and a $2\frac{1}{2}$-inch cast iron pipe was fixed at the higher end of the pipe drain for ventilating the same: the whole surface of the gully was finished either with stone paving or with cement plaster.

This system was generally found unsatisfactory, as the traps and pipe drains quickly choked with household rubbish or refuse from the nahanis, which resulted in the paving being flooded and the general condition of things being no better than if no pipe drain existed. In time, owing to the constant sweeping and flushing, the stones forming the pavement of the gully became uneven, the joints opened, and the sewage and sullage soaked into the foundations of the houses. For such a class of property, situate in the heart of a thickly populated city, it was necessary, therefore, to design some better system.

The system now prevalent and one that has given great satisfaction, is to construct open drains in all such gullies. These open drains, which are more fully described hereafter, are 4 inches wide by 10 inches to 11 inches in depth and are constructed at a gradient of not less than 1 in 100. They have the great advantage of being easily swept clean, and, though rubbish may choke them, it can only do so temporarily.

It is essential that proper care should be taken to prevent foul air from the sewer entering the houses. This is more important in the East than in Europe, not only on account of the higher temperature but also because the tenants of the house often live, eat, and sleep in the room where the nahani with its pipe connection is situated.

The depth of the seal in any trap for house drains in India should never be less than three inches. Traps can never be absolutely relied upon, and should be regarded more in the light of a necessary evil, which it seems impossible at present to improve upon: they fail from various causes, such as sewer air forcing its way through them under pressure, evaporation of water in the trap, siphonage due to a piece of rag or paper being caught part way,

and from the water being removed on account of a partial vacuum due to a sudden discharge of water down the pipe connected with them.

Under any circumstances, house connections are an expensive item, and they should therefore be kept as simple as possible consistent with efficiency.

The following few rules may be considered to be applicable to general house-connection work in India, when for any reasons it is preferable to use pipe drains :—

The branch pipe drain connecting a house with the street sewer should be always of well burnt stoneware, and of a minimum size of four inches in diameter, while the gradients of such pipes should not be less than 1 in 50.

All such pipe drains should be laid in straight lines with true gradients from one inspection chamber to the other. An inspection chamber should be constructed at every angle in the drain and on long straight lengths at distances of 100 feet.

All pipes should first be laid and fitted dry, previous to any jointing being done. All joints should be made with cement and tarred gasket as hereafter described.

Before being covered in, the joints of the pipe drain should be tested for water tightness by closing the lower end of the length of pipes and filling it with water to the level of six inches above the top of the highest pipe. If the level of the water does not fall within one hour, the joints may be considered satisfactory.

All inlets to pipe drains should be trapped with the exception of those used for ventilation.

The higher end of the pipe drain should be finished with, preferably, an inspection chamber provided with a ventilating pipe.

Excessive and unnecessary depth of excavation should be avoided.

In the event of a satisfactory gradient not being obtainable, arrangements for sufficient flushing to produce a self-cleansing velocity must be provided.

Plates 37 and 38 shew, respectively, the class of stoneware and cast-iron pipes and fittings used in house-connection works in Bombay. It has been the practice to use 6-inch pipes for all branch drains, except those of very short lengths. This size is in many cases, theoretically, too large for the maximum amount of sewage which the pipes will ever be called upon to discharge, but is adopted for the reason that so much solid matter in the way of sand, ashes, and vegetable refuse is discharged into the branch drains, that pipes of less diameter would constantly become choked.

The intercepting sewer trap shewn in Plate 36 is one of the most general traps in use. It is usually fixed in an inspection chamber built at the lower end of the house pipe drain, of a size sufficient to allow of a cleaning rod being easily manipulated. It is provided with a cleaning eye, by means of which any obstruction in the drain between the trap and the public sewer in the street can be removed without disturbing the surface of the road.

The question whether the intercepting sewer trap is or is not desirable, has been freely discussed among Sanitary Engineers. This particular kind of trap was introduced shortly after the illness of King Edward VII (then Prince of Wales), which was attributed to bad drainage. There are many Sanitary Engineers who blame this trap for an increase in the foulness of sewer air and assert that it should be discarded. Certainly, the trap, especially when connected to a 6-inch pipe drain, is not often completely flushed out, and organic matter in course of putrefaction remains in it and often becomes very offensive.

The discussion in regard to the use of the "intercepting trap" became so acute, that in October 1908 the Right Hon. John Burns, M.P., then President of the Local Government Board, appointed a departmental Committee to enquire into the matter.

This Committee sat until December 1914, and went most exhaustively into the question, making practical experiments, and taking the evidence of many well known Medical Officers of Health, and Sanitary Engineers.

The results of that enquiry have been published in a Blue Book, and are no doubt well known to many Sanitary Engineers, but it will be well to state here a few of the conclusions arrived at.

The Committee state that the disadvantages involved by the use of the intercepting trap are substantial and of serious practical importance, and that the construction of house drainage may be simplified by its omission, but these disadvantages may to some extent be obviated, without omitting the trap altogether. The tendency of the intercepting trap is to retain a considerable portion of the solid matter in sewage, varying from 42 to 47 per cent. a fact which undoubtedly favours the blocking of the trap as well as the putrefaction of the sewage before it reaches the sewers. This trouble may be diminished by using a trap of smaller diameter than is customary. The liability of the intercepting trap to become blocked appears however to be insuperable, and it is this which constitutes its most serious disadvantage.

The evil of this blocking can also be minimised, the Committee say, by constructing the house drain in iron pipes, and by closing with a removable cover the usual channel in the inspection chamber, the object of this measure being to insure that the effect of a block in the intercepting trap may become evident as early as possible. However the Committee state that the intercepting trap is not without its advantages, as it does serve as an effectual barrier to the entry of sewer air into the house drain, and this is the fundamental advantage claimed for it.

Experiments show that the trap is not liable to be forced and rendered useless by pressure of air from the sewer. The entry of sewer air into dwellings through the house drain may be excluded, if the house drain is constructed of iron pipes, or if stoneware pipes are very carefully laid and tested before they are put into

use, so as to exclude any chance of leakage, and further if all down-take pipes, as is almost universally the case, are protected at their junctions with baths, W. Cs., etc., by good traps, then there is no reason to suppose that sewer air will find its way into dwellings. Again Bacteriological evidence has shown that the micro-organisms in sewage are very rarely present in sewer air, and that they are more liable to be in drain air. This is another argument against the intercepting trap, with its liability to blocking, and to the holding up of purifying sewage.

The necessity for the intercepting trap on Bacteriological and Epidemiological grounds was not established by the investigations of the Committee, but it is at the same time very difficult to lay down any general rule in regard to it. It has been the Author's experience in Eastern countries, where the successful work of house drainage is as yet hardly generally appreciated, that all sorts of things, to save trouble, are disposed of through the water-closets by servants; towels, dusters, rags of all description, and often half worn out brushes are passed through the traps, and often by means of force. This practice invariably leads to the blockage of the trap.

In Cairo this was certainly the case, and although in the first instance, in a part of the suburbs, the Author fixed intercepting traps, at a later date, and in the City proper, no intercepting traps have been fixed, nor is it the custom in Continental drainage schemes to make use of this trap.

In house drainage installations without an intercepting trap it is a desideratum that all house pipes should be most carefully trapped, and jointed and carried well above the eaves of the houses, with their ends protected by wire domes to prevent birds from nesting, and all pipes should be dipped in Dr. Angus Smith's solution, or some other similar solution, to prevent rusting on the inside.

There are various kinds of junction pipes shewn in Plate 37. Such junctions should either be quadrant or oblique; and the use of T junctions should be avoided, because these direct the flow of

sewage at right angles, instead of obliquely, in the direction of the flow of sewage in the main pipe.

The 6 inches by 6 inches stoneware trap, with a 4-inch outlet, is a common and useful fitting; and where a closed pipe drain is the main conduit for conveying the house sullage to the sewer one should always be inserted at the bottom of every waste water down-take pipe to receive the sullage from nahani and washing places.

All waste water pipes should be 3 inches in diameter and the joints should be made air-tight with a mixture composed of Portland cement, boiled oil, and chopped hemp, a ring of tarred gasket being first inserted into the joint.

Soil pipes should be universally 4 inches in diameter. The thickness of waste water pipes and soil pipes will vary, but it should not be less than ⅛th of an inch in the case of the former and 3-16ths of an inch in that of the latter.

The trap shewn in Plate 38 is inserted in a nahani to prevent the foul air in the down-take pipe from entering the building.

All cast iron pipes and fittings used for house drainage purposes should be coated with Dr. Angus Smith's solution before use.

The following is the method by which pipes are coated with this solution:—

A tank or bath required for the above process should be of sufficient capacity to allow of the complete immersion of the largest size of pipe to be coated, and should be externally fired in such a manner that the heat from the furnace is evenly distributed over the bottom of the tank.

The coating mixture is made from coal pitch, distilled until all the naphtha is removed, or what is known as Burgundy pitch, and 6 per cent. by weight of boiled linseed oil. Pitch which becomes hard and brittle when cold, should be rejected.

The pipes, which must be thoroughly clean and free from rust, are immersed in the bath when its temperature has arisen to 300°F., and are kept there until they have attained the

same temperature; after removal they should be placed on end to drain.

The bath requires careful attention and should be kept, as far as possible, at an even temperature. Overheating will result in the contents boiling over and insufficient heat will produce too thick a coating.

The mixture will after long use become thick, when a little more oil may be added, but when too thick to produce an even and thin coating it should be removed and fresh materials substituted. Coal tar must on no account be used for thinning as it will cause the bath to foam.

All inspection chambers should be constructed of 9-inch brickwork, internally plastered with a half-inch coating of cement and sand (1 to 1). At the bottom of the chamber a channel with a half round pipe, of the width and the full depth of the pipe drain, should be constructed. The chamber should be covered with a cast iron air tight frame and cover as shewn in Fig. 27.

FIG. 27.

The experience after several years' trial in Bombay in houses with gullies, is that the drain for the conveyance of the house sullage, except the street portion, is better open than closed. This conclusion has been arrived at on account of the liability of the closed drain to chokage, due to the large amount of all kinds of solid matter deliberately or carelessly put into the drain by the inmates of houses.

The width of the gullies between houses varies from 1 foot to 3 feet or more. In the case of narrow gullies the open drain may be constructed in the centre, any rain water falling on the gully being allowed to flow away with the sullage. In wider gullies the drain should be constructed on one side, as shewn in Fig. 28, and the storm-water channel on the other. In the case where two open

drains are constructed, one on each side, the storm-water channel should be laid in the centre.

The class of open drain found most satisfactory is that shewn in Fig. 28. It may be constructed either in the centre or on one side of the house-gully. The invert is lined with 4 inch channel pipes and the remainder, which is of brickwork, is covered with a half-inch coating of cement and sand (1 to 1).

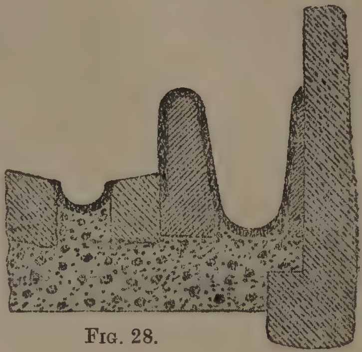


FIG. 28.

The drain is very easily flushed and kept clean; and at the end—between it and the inspection chambers which contain the intercepting sewer trap—is constructed a small silt chamber with a cast iron grating as shewn in Fig. 29. If these small chambers

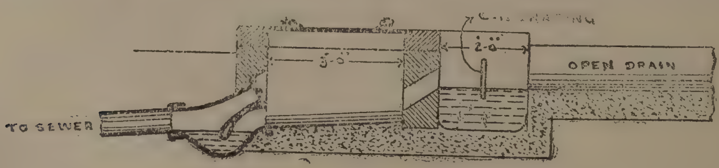


FIG. 29.

are regularly emptied, the success of the open drain is assured. The minimum gradient at which these open drains should be constructed is 1 in 100.

The practice in Bombay and in Cairo is for the house owner to construct the house drain up to the boundary of his property, as also the inspection chamber with the intercepting sewer trap and the ventilating pipe on the street end of the drain; and for the Municipal Corporation to lay the connecting closed drain in the public street. The "street connection," as this connecting drain is called, should generally consist of a 5 or 6-inch pipe drain, which is connected to the street sewer by means of a junction pipe, or in

the event of there being no junction pipe, by means of a saddle piece as shewn in Fig. 30.

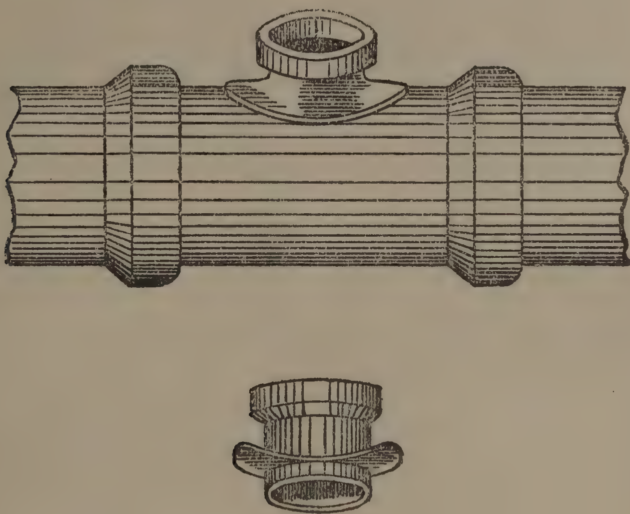


FIG. 30.

An open drain is not applicable to any house where water-closets are in use. For such houses a closed drain must be laid for both sullage and fœcal matter as before described, or an open drain should be constructed for the sullage and a closed one for fœcal matter.

It will be many years before the use of water-closets in any Indian City will become general. The habits of the people are in many ways not suited to them, and caste prejudices often interpose. Wherever practicable, and in the case of houses occupied by the higher class of Natives and Europeans, water-closets are desirable. Various kinds of soil pans for water-closets suitable for Indians are now made, and a more detailed description of those patterns has been given in Chapter III. For Europeans, similar soil pans to those used in Europe are suitable here; but preference should always be given to a wash-down pattern as there is less area to foul. All water-closets, whether for Indians or Europeans, should be

flushed by means of a three-gallon flush tank, a water-supply tank being provided in a suitable position.

In hotels, clubs, and other institutions, where hand basins are provided and urinals, apart from water-closets, are generally considered necessary, there is practically no departure made in either the construction or method of drainage from the ordinary English practice. In buildings set apart for the sole use of Europeans. urinal basins are generally used, and for Indians the pattern shewn in Plate 21 will be found perfectly satisfactory. Such appliances should always be placed against an exterior wall, so that a length of pipe drain under the floor of the building may be avoided. Should however it be necessary to lay a pipe under any part of a building, it should invariably be of cast iron and embedded in concrete. Efficient flushing appliances are essential and a reliable and ample water-supply is imperative. Anything more offensive and dangerous than a water-closet without water in hot tropical weather it would be hardly possible to imagine.

The building bye-laws in Bombay now specify that all water-closets and privies should be cut off from any living room by at least a three-foot air space on all sides; but this rule has only come into force in recent years, and in the majority of houses in the City the privies are not detached in any way from the main building, but on the other hand are often built against an interior wall in a convenient position. Plate 39 shews in detail the class of privy to be found in most Indian houses. Such a privy, from a sanitary point of view, must be considered insanitary. Looking, however, to the present sanitary education of the people, it is probably the best arrangement that can be provided when a water-closet is out of place, and it falls in with the caste prejudices of the people, who prefer it to all other arrangements. The sloping part of the privy which receives the night-soil, and the sides, should preferably be lined with plate glass, as this material is not only incorrodible, but fœcal matter does not readily cling to its surface.

The privies are usually connected with a shaft, constructed of brick-masonry, plastered with lime or cement, and of an internal measurement of 18 inches by 18 inches. But latterly these masonry shafts have been replaced by 6-inch stoneware pipes—an undoubted improvement. After a time, these shafts must naturally get coated with fœcal matter and become insanitary, as they have no flushing arrangements and their state of cleanliness depends solely on the amount of water thrown down them by hand through the privies. The shaft discharges its contents into a basket as previously described.

Some years ago, the Author designed and carried out an intermediate system to be used in connection with privies. This consisted of the substitution for the usual basket of a stoneware soil pan at the bottom of the shaft. Into this pan everything from the privy was discharged. An automatic flushing tank was fixed on the wall outside the privy, containing from 10 to 20 gallons of water according to the number of privy seats. It was connected with the soil pan, and on the water being discharged the contents were flushed through a trap into a branch drain connected with the sewer. The soil pan was made of such a shape that solid matter such as stones and tiles were retained in it, and the sole work of the sweeper was to remove these materials, everything soluble being flushed away. The flushing tank, besides being automatic, can also be discharged at will by the sweeper when only partly full.

This arrangement proved to be useful and sanitary and free from smell, and did away with the hand removal of fæces; but it proved wasteful in regard to the amount of water used.

Plate 40 shews the above system in detail.

The universal term nahani is used to describe a small sink in an Indian house, with or without a water connection either inside or outside a room, built primarily for washing purposes, but often used indiscriminately for urinating and defæcating, particularly by children. It is usually about 3 feet square, constructed in a corner and raised some 4 inches above the surface of the floor, with a

concrete or brick-work surface plastered with lime or cement, and surrounded on the open sides by a small kerb or a dwarf wall. All nahanis are connected to the waste water pipe fixed to the outside of the house by means of a nahani trap, previously described, or a Tee-shaped pipe. If the latter is used, the discharge into the waste water pipe is through a cistern head, but in the case of a nahani trap, it is connected direct with the waste water pipe which is carried up above the building as hereinafter described.

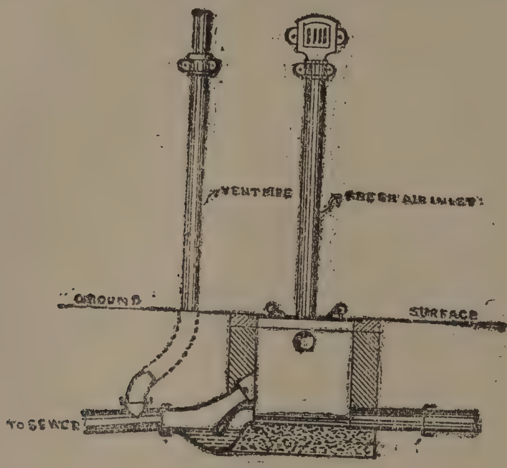


FIG. 31.

Ventilating Pipes.—No house drainage would be complete without a regular system of ventilation. The theory of ventilation is that (*a*) the air of the drain being at a higher temperature than the external air and therefore lighter, a current is formed through the outlet shaft ; (*b*) that the warm air, carrying a certain amount of water vapour which is lighter than dry air, causes it to rise ; (*c*) that wind blowing across the open end of the outlet shaft creates a slight vacuum. On the sewer side of the intercepting trap, a 3-inch cast iron pipe should be fixed to the drain and carried up the side of the house to a height of five feet above the eaves of any roof that may be within twenty feet thereof. The inspection

chamber at the lower end of the pipe drain should be connected with a fresh air inlet pipe fitted with a mica valve as shewn in Fig. 31. This fresh air inlet pipe should be placed against a wall or a post, whichever is most convenient, and should be about six feet above ground level. The head of every pipe drain should be ventilated with a 3-inch cast iron ventilating pipe, similar to the one hereinbefore described. In the event of a pipe drain being more than 100 feet in length, a ventilating pipe should be fixed midway and connected with the intermediate inspection chamber. All soil pipes should be carried up to five feet above the eaves of the roof. In case of a tier of water-closets one above the other, a 2-inch anti-siphon pipe should be taken from each water-closet, except from the one on the highest floor, and carried up above the roof the same height as the soil pipe. In the event of waste water pipes being fitted with nahani traps, each of these pipes should be carried up as a ventilating pipe five feet above the eaves of the roof of the house. All such pipes carried up above the roof should be protected at the top with a wire dome.

Gullies.—As already stated gullies are the narrow passages left between houses for drainage purposes and also to give access to the privies and to admit light and air. Such gullies should always be paved with a non-porous stone set in concrete and jointed with cement, or should be constructed of concrete finished off with a coating of cement plastering (1 to 1) one inch in thickness: the surface of the gully should slope towards the centre as shewn in Fig. 32 and also longitudinally towards the street.

FIG. 32.

At the lower end of the gully and in the centre of it a jump-weir should be constructed as shewn in Fig. 33, so that while any ordinary flow of sewage would discharge over the jump-weir into a trap connected with the sewer, a rush of storm-water would pass

over the opening and discharge into another trap connected with the storm-water drain. In the event of its being considered necessary to flush the gully a flushing tank as shown in Plate 41 will be found suitable. This tank is fitted with an annular siphon and a reverse ball valve and should have a capacity of from 20 to 50 gallons.

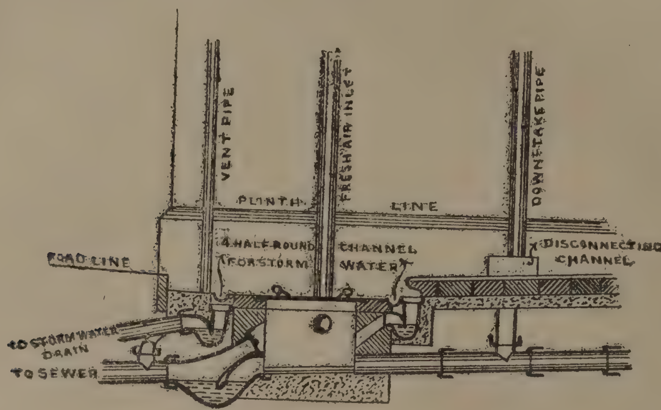


FIG. 33.

All down-take pipes, ventilating pipes, and soil pipes should be tested for efficiency and soundness by means of the smoke test as follows :—A smoke rocket should be inserted in the bottom of the cast iron pipe, if it is not connected directly with the drain, or, if otherwise, into the inlet in the nearest inspection chamber, and fixed there so that all the smoke will pass up the pipe. As soon as the smoke commences to issue from the top of the ventilating pipe the pipe should be closed at its top end to enable the smoke under pressure to find its way out of any leaky joints or cracks or perforations in the pipe.

For house connection purposes, houses in the City of Bombay are divided into the following three classes :—

CLASS I.—Detached houses in compounds.

CLASS II.—Attached houses without gullies.

CLASS III.—Houses of all other classes.

These classes are further sub-divided into (A) and (B) thus :—

SUB-CLASS A.—Houses where it is desirable to drain the premises by a pipe drain.

SUB-CLASS B.—Houses which are not within 100 feet of a Municipal sewer.

CLASS I.—With houses of this class, open drains as branch drains should be made use of as far as possible, but where water-closets are constructed, then the branch drains connected with the closets must be closed.

CLASS II.—In houses of this class, an open drain is not possible, and therefore the closed pipe drain must be laid under the building.

The conditions laid down in Bombay in regard to the construction of drains which have to be laid to pass beneath any part of a dwelling house are as follow :—

"Every owner shall so construct a drain only when any other mode of construction is impracticable, and not even then without the written permission of the Municipal Commissioner. It should be so laid that there shall be, between the top of the pipe and the surface of the ground under such building, a depth at least equal to twice the internal diameter of the pipe drain.

"The drain preferably of cast iron shall be laid in a straight line for the whole of the distance beneath the building and be completely embedded in and covered with good concrete nowhere less thick than 6 inches outside the drain, measured, in any direction.

"At each end of such portion of the drain, beneath the building, a 6-inch trap shall be inserted outside the building, giving a drop of at least 2 inches into the contained water with a 4-inch inspection inlet brought up to within 9 inches of the surface, and covered with a cast iron grating 9 inches by 9 inches set in a frame of stone or timber standing up 2 inches above the general surface so as to exclude storm-water. On the lower side of the siphon, a 4-inch stoneware branch pipe

shall be connected with the drain and brought up above the ground and continued with a cast iron pipe above the roof of the building for ventilation purposes, in addition to such means of ventilation as are ordinarily directed to be provided."

CLASS III.—In all such houses, the premises shall be drained by means of an open drain. The only exception to this is in the case where one or more sides of a house abut on a public road, under which circumstances there is no alternative but to provide a closed pipe drain. In houses of this class also, where water-closets are constructed, closed pipe drains must always be laid.

SUB-CLASS A.—In regard to this class of houses, sanction is accorded to owners desirous of having closed drains, instead of open, but in such cases the following conditions are laid down :—

"The pipe drain shall be laid at a gradient of not less than 1 in 50. The connection between the street connection pipe and the branch drain with the inspection chamber, the intercepting sewer trap, and the fresh air inlet pipe, shall be made at the house-owner's expense. Inspection chambers shall be placed at every 100 feet or less if there is any change of direction, and built in accordance with the conditions prescribed in the earlier part of this Chapter. The branch drain must be ventilated by a 3-inch cast iron ventilating pipe, and every ventilating pipe, soil pipe, and anti-siphon pipe must be protected at the top by a wire dome and carried up in accordance with the conditions before laid down. Nahani traps shall be provided for every nahani except those on the ground floor. All waste-water pipes must be of cast iron three inches in diameter, and all soil pipes four inches in diameter. All soil pans for water-closets must be of porcelain or glazed stoneware, provided with a flushing rim and a trap of similar material. Every water-closet must be provided with a 3-gallon tank for flushing purposes ; and in cases

of tiers of water-closets, the anti-siphonage pipes must be fixed as hereinbefore described."

SUB-CLASS B.—In regard to this class of buildings, there is at present no law by which the Corporation of Bombay can compel the house-owner to connect his premises with a Municipal sewer in the public roads. In such cases it often happens that there is no sewer except at a very considerable distance from the house, and therefore, unless it is practicable to sanitarily dispose of the sullage in a garden for the irrigation of plants, it must be drained into a cess-pool. In a case where a cess-pool is constructed, its capacity below the invert of the drain discharging into it should be sufficient to hold a twenty-four hours' flow. Such a cess-pool should be ventilated by a cast iron or galvanized iron pipe, not less than three inches in diameter, and of such a height as to ensure its causing no nuisance.

It is desirable to have a cess-pool for privies separate from that for nahanis and the size of this cess-pool should be calculated to have a capacity of 3 cubic feet per privy seat with a minimum of 10 cubic feet.

Cess-pools should always be emptied once every twenty-four hours, and preferably at night.

Such a cess-pool should be constructed of brickwork on concrete internally rendered with a $\frac{1}{2}$-inch layer of cement and sand (1 to 1). The walls of the cess-pool should be brought up to six inches above the surface of the ground, so that surface water may not be able to flow into it, and covered with an air-tight cover to prevent noxious odours escaping.

No cess-pool should be constructed within 20 feet of any well used for drinking purposes, for although the cess-pool may be constructed so as to be perfectly water-tight, it is always liable to overflow.

It is desirable also in houses of this class to make use of open drains rather than closed drains. Many instances are within the knowledge of the Author where the sewage of such buildings has

been successfully dealt with by small Septic Tanks and Filters or by a series of filters, the effluent being run into masonry tanks and used for gardening purposes, or discharged into perforated stoneware pipes surrounded by broken stone laid some 3′-0″ below the surface of the ground ; this has been found a most successful method in Egypt. Such arrangements, if constructed scientifically, are quite satisfactory.

Plate 42 shews a house fitted with water-closets and drained, according to the arrangements already advocated, by means of a 6-inch pipe drain. It will be seen that the drain is laid at a gradient of 1 in 50, and that at its higher end there is an inspection chamber covered with an air-tight cast iron frame and cover. Connected to this inspection chamber is a 4-inch cast iron soil pipe from the water-closets. At the lower end of the pipe drain is another inspection chamber, into the brickwork of which is built an intercepting sewer-trap with a cleaning eye : the cap of this cleaning eye should always be securely fixed, as otherwise gas from the sewer will have a free discharge into the chamber. Connected with this chamber there is also a 3-inch fresh air inlet pipe fitted with a mica flap valve, which supplies fresh air to the whole length of the pipe drain between the inspection chambers. Under each waste-water pipe is fixed a 6-inch by 4-inch trap, which is connected to the pipe drain by means of a 4-inch branch pipe.

All the waste-water pipes are three inches in diameter, coated with Dr. Angus Smith's solution, and carried up five feet above the eaves of the roof, the ends being protected with wire-domes. The nahanis on each of the floors are connected with the waste-water pipes by means of nahani traps. The soil pipe from the water-closets is four inches in diameter, and is also carried up five feet above the eaves of the roof of the house. Each soil pan is trapped and connected with the soil pipe by means of 3-inch branches. Alongside the soil pipe is a 2-inch anti-siphon pipe connected to the traps of the soil pans on the ground and first floors. A strong tank is fixed above the water-closets to provide a constant

supply of water to the 3-gallon tanks for flushing the water-closets.

Connected with the pipe drain and between the intercepting trap and the sewer is a 3-inch ventilating pipe, which is carried up the side of the house to five feet above the eaves of the roof, thus preventing the seal in the trap being forced by a pressure of gas in the sewer. The fresh air, which enters by means of the mica flap valve connected with the inspection chamber at the lower end of the pipe drain, is discharged at the higher end of the drain through the ventilating pipe which is connected to the inspection chamber at that end. All soil pipes and waste-water pipes are trapped at their connections with the buildings and carried up above the roofs as ventilating pipes. Each waste-water pipe is disconnected from the pipe drain at the bottom, and discharges its sullage through a short length of channel into a trap. The water-closets are entirely separated from the main buildings by a passage 3 feet wide.

It will thus be seen that the whole of the building is guarded against air entering it from the sewer or pipe drain.

The storm-water falling on the gully is discharged over a jump-weir into a trap connected with a storm-water drain in the street.

Plate 43 shews the same class of building with Native privies and drained by means of an open drain. The open drain is constructed, as described earlier in this Chapter, at a gradient of 1 in 100, and at its lower end it discharges into a small catch-pit fitted with a grating. This catch-pit is to arrest heavy matter in the sewage, and the grating is to intercept floating substances, such as leaves, etc. The sullage, after passing through the catch-pit may discharge into an inspection chamber, into the wall of which is built the intercepting sewer trap, as explained in the description of the previous house.

The privy sullage discharges on to the higher end of the open drain through the open sides of the basket placed under the shaft of the privy. The waste-water pipes discharge directly on to the

open drain without any traps. In two instances in this house the discharge from nahanis is directly on to cistern heads, but in one instance the nahanis discharge through nahani traps, as explained in the description of the previous house, and in this case the waste-water pipe is carried up above the eaves of the roof and finished with a wire-dome.

The privies are separated from the main building by a passage three feet wide, and discharge their contents into a 6-inch stoneware pipe acting as a privy shaft. The ventilation of the sewer is provided for by a 4-inch stoneware pipe connected with the 6-inch pipe drain on the sewer side of the intercepting sewer trap, and continued by a 3-inch cast iron pipe carried up above the eaves o the roof of the house and finished with a wire-dome. The storm-water from the gully is discharged by means of a jump-weir into a trap fixed at the lower end, and connected with the storm-water drain in the street.

It may be argued, perhaps rightly, that the house connections described in this Chapter are in many ways too complicated and expensive, except for large cities with high buildings, and that in a mofussil town something much simpler would suffice. Some years ago the Author visited Secunderabad to advise on the drainage of the town, including the house connections. After inspecting many of the houses, the arrangement as shewn in Plate 44 was recommended. This consisted in connecting the washing place or nahani at the back of the house by means of a 4-inch by 4-inch stoneware trap and a 4-inch stoneware pipe to the pipe sewer in the street. On the same line of the 4-inch pipe, but lower down than the nahani, is connected the privy of the premises, fæces being caught in a basket and the sullage draining through a 4-inch by 4-inch stoneware trap to the 4-inch pipe drain.

At first it would appear that the absence of any sewer trap near the junction of the house drain with the sewer would be likely to allow sewer air to pass up the house drain and, in the event of the water in the traps having evaporated, escaping within the precincts

of the houses. On the other hand, however, it must be remembered that practically no night-soil passed into the sewers, and that the sewage was of a weak and more or less inoffensive nature. It was, therefore, very improbable that any serious accumulation of

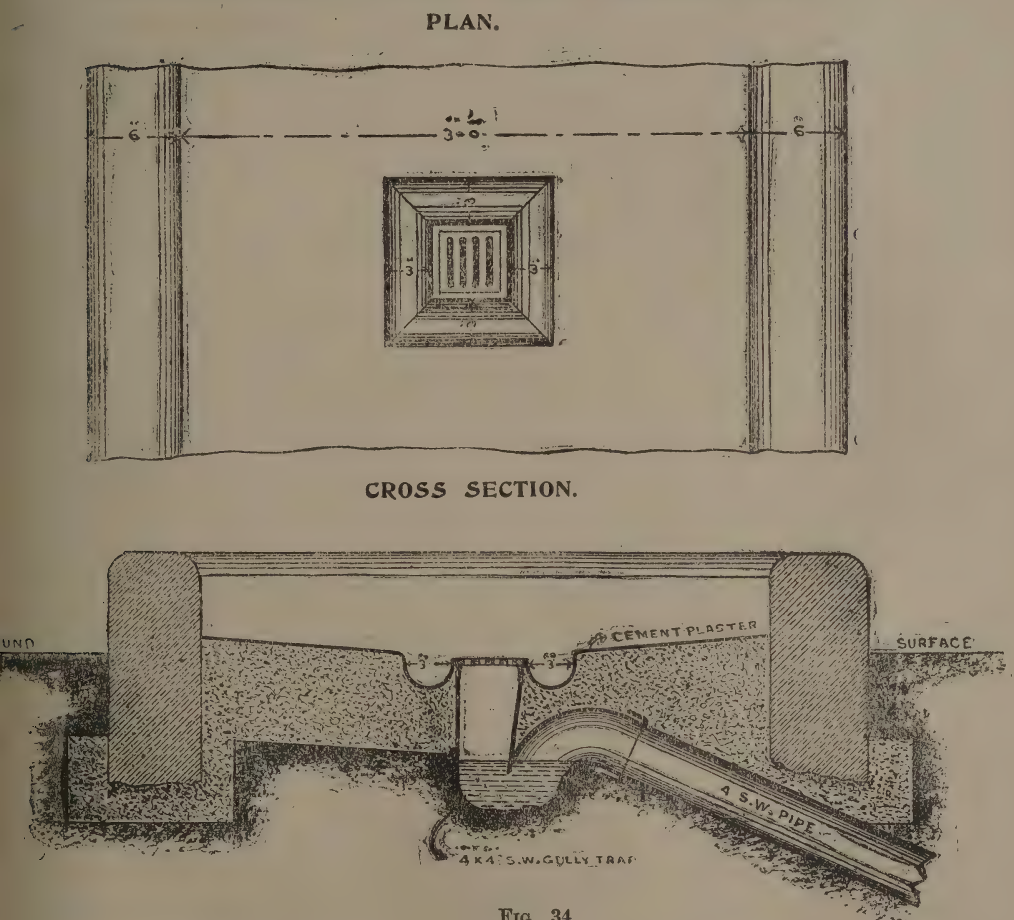


FIG. 34.

sewer air would take place, and even if this remote contingency did arise and a nuisance was noticed, such nuisance would be easily remedied by pouring a little water into the traps. Further, no connections of any kind were made with the interior of the houses,

and taking all these facts into consideration, the Author was satisfied that such a comparatively expensive accessory as a sewer trap could in this instance be dispensed with.

The end of the 4-inch drain should be ventilated by means of a 3-inch pipe, carried up above the roof or fixed on a post ten feet above the ground ; but if for economy it is desired not to erect a ventilating pipe in all cases, it may only be done at the higher parts of the district.

A washing place may be constructed of any size to suit the premises for which it is intended. It should be built of concrete rendered with cement plaster, the walls surrounding it being of brickwork ; three sides may be raised, if desired, to a height convenient for privacy.

The slope of the washing place should be towards the trap, which should be covered with a grating.

This arrangement is economical and eminently suitable for the one-storeyed buildings with small compounds which are mostly met with in the mofussil towns, and might be applied in many of the old houses in villages.

Fig. 34 represents a detail drawing of the plan and cross-section of the washing place referred to above.

In the out-lying villages of Bombay, where drainage is necessary, public detached washing places and latrines for the use of small and poorly-built houses should be erected, instead of eachi ndividual house being given its own convenience connected with the pipe sewer.

Drainage of Horse Stables.—Much experience and knowledge have been obtained in Bombay as to the best method of draining stables, for there are many very large stables for the reception and sale of the immense numbers of Arab and Australian horses which are annually imported.

For horse stables, both public and private, it is a good plan to construct the floor of each stall with a layer of 6-inches of lime concrete laid at a slope of 3-inches in 9 feet or 1 in 36. Above the

concrete should be spread a 3-inch layer of good muram well ramme and finished off to the same slope as the concrete. Meeting the muram and at right angles to the stall should be constructed a V-shaped channel, 12 inches wide, formed of stone or other suitable material. Muram is only advantageous when it is carefully looked after, and any hollows formed by the feet of the horse should be quickly filled up and rammed. Muram is not a suitable material if not kept in repair. Another arrangement is to plaster the concrete with lime, forming a small channel in the centre of the stall to meet the V-shaped channel at the front. Stone is not a suitable material with which to pave horse stables. It is very hard and apt to become under certain conditions slippery, and in the event of a horse falling on it great damage is often done to the animal. The channel in front of the stall should have a gradient not less than 1 in 100 discharging into a 6-inch stoneware trap connected to the branch drain. In England, brick with corrugations is much used for the paving of stables. This probably is the best method of all; but in the East, as a rule, suitable bricks for the purpose are not easily obtainable.

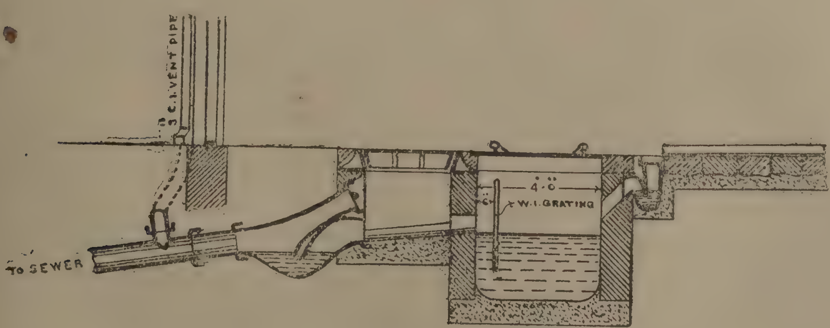


FIG. 35.

Buffalo Milch Cattle Stables.—In this class of stables muram is of no use, and the floor of every such stable should be paved over the whole area with stone paving laid on a 6-inch bed of

concrete. This is rendered necessary because of the frequent washing which buffaloes receive daily. The paving should slope at an inclination of 1 in 60 towards an open stone channel. The channel, as in the case of horse stables, should be V-shaped with a gradient of 1 in 60 towards a trap on the branch pipe drain. In connection with a stable of this class, and on account of the large quantity of solid matter carried in the sewage, a catch-pit should be constructed as in Fig. 35. During the dry season much of the buffalo excreta is removed by hand and, mixed with hay or straw and the sifting of cotton seed, made into cakes for fuel purposes. These cakes, when dried in the sun, are ready for use, and in many parts of India are almost the only fuel available. The catch-pit should be placed at a point where the stable drain ends and the branch pipe drain commences. It should be 3 feet by 4 feet by 5 feet deep, and be provided with a wrought-iron grating, the bars of which should be fixed half an inch apart to prevent the stable litter passing through into the branch drains.

Bullock Stables.—As a general rule, no special drainage is required for bullock stables, a foundation of good well rammed muram being all that is necessary, for the droppings of bullocks are much in request and are largely used for the plastering of the floors of living rooms which have earthen floors. Mixed with fine red earth, bullock excreta form a plaster which has a considerable binding property, and is rendered by the ammonia contained in it a safeguard against fleas and other vermin.

CHAPTER

Sewage Disposal

The best method of sewage disposal is always a most difficult question to decide, as a false move may often have far reaching and very serious consequences. The question therefore should invariably be given the most deliberate and painstaking consideration. The difficulties which are met with in many inland English towns do not as yet exist in the East. Land in England is often only available at a prohibitive price, and legislative restrictions are rightly placed on the discharge of sewage into rivers.

The different systems of disposal, any of which may be adopted according to local circumstances, may be classified as follows :—

(1) Dry Earth.
(2) River Outfall.
(3) Sea Outfall.
(4) Land Irrigation.
(5) Precipitation.
(6) Electrolysed Sea Water.
(7) Biological Treatment.

Dry Earth.—In India, and in fact in most Eastern countries, the dry-earth system was the earliest method adopted for the disposal of sewage and is even now very usual. In sparsely populated districts, this system, if efficiently carried out, still finds approval. The fæcal matter is collected, removed, and buried outside the town. The sullage water, if not removed by carts finds its way through open channels to pits, where it is allowed to soak into the ground. The usual procedure is to remove the fæcal matter to trenches and cover it with earth, and the mistake

is often made of excavating these trenches too deep to allow of the bacteria dealing efficiently with the fæces. Trenches should be three feet wide by nine inches deep and one foot apart, and covered with soil slightly raised above the surrounding level.

With increased education and the march of science in sanitation, this system of disposal is doomed and calls for no further comment.

River Outfalls.—The sewage of towns situatde on the banks of rivers is usually discharged into these rivers, but this should never be done without some preparatory treatment. The degree of purification required depends upon the relative volume of the sewage to the minimum flow of the river, and in cases where, compared with the amount of sewage, the volume of the river is large, it is not generally necessary to construct works which are expensive or of great magnitude, as the river may be safely relied upon to complete the final purification of the effluent.

Unfortunately, however, the authorities of many Indian towns situated on the banks of large rivers give little consideration to the pollution of such rivers, and make no attempt to purify the sewage before it is discharged into them. Many of the rivers are sacred; yet the water from these and all others that are perennial is generally used by the inhabitants on their banks for drinking, bathing, and all other domestic purposes, so that the discharge of crude sewage into them becomes little short of criminal; and there is no doubt that such neglect is responsible for the occurrence of cholera and other diseases in epidemic form in many of the towns of India. Rivers in India are apt to run so perilously low in the hot season that under no circumstances whatever should sewage be permitted to be discharged into them without having previously been submitted to some form of purification. Suitable land is always available and any large expenditure on works rarely necessary.

The Author feels that in connection with River Outfalls he cannot do better than quote from the conclusions arrived at by the Commissioners of the "Royal Commission on Sewage Disposal," published in their 8th Report.

The Commission sat for enquiry into the disposal of sewage in streams and rivers, during the years 1909 to 1912, and their Report was published in March 1913.

The conclusions have been arrived at after a large amount of enquiry, experiments and of analyses, and must be considered to embody the latest knowledge available on this subject.

The chemical changes which arise in polluted water were dealt with by Dr. Adney in the 5th Report of the Commission, in which he stated "that the most important change which occurs in an unpolluted water when it is mixed with sewage or other waterborne refuse matter is the more or less rapid absorption of its dissolved oxygen."

The test decided on by the Commission in its 8th Report is that the amount of dissolved oxygen observed in 5 days should not exceed more than 0·4 gram per 100,000 cubic centimetres of water, this being a limit not to be exceeded without signs of pollution being likely to manifest themselves.

This test represents more naturally the actual process by which the more readily oxidisable constituents of the polluting matter absorb the oxygen dissolved in the river water. Temperature is however an important factor, and tests should not be carried out at different temperatures; the experiments made by the Commission have invariably been at one temperature, *viz.*, 65° F.

A large factor in considering a standard for pollution of streams and rivers is the quality of the water in such streams, and its dilution properties. The importance of this latter is shown by numerous instances where the amount of dilution is sufficient to practically do the whole work of Sewage Purification by natural agencies.

In the 5th Report of the Commission, it was stated that the amount of suspended solids contained in an effluent after complete treatment should not contain more than 3 parts per 100,000, and this is reiterated in the 8th Report, and in the dissolved oxygen test it lays down, that the effluent should not take up more than

2 parts of dissolved oxygen per 100,000 in five days at a temperature of 65° F.; but the Commission state that if the dilution of a river or stream is sufficient to permit the discharge of sewage into it with or without treatment, the dissolved oxygen test might be dispensed with as a standard, but they suggest that the standard of 6 parts of solid matter per 100,000 parts be adopted, where the dilution is not less than 150 volumes and does not exceed 300 volumes, and where the dilution is more than 300 volumes but less than 500 volumes, 15 parts of suspended solids per 100,000 might be permissible. Where the dilution is so great, say over 500 volumes, no treatment would be considered necessary. The Commission however consider it is of great importance if only for the sake of appearance that the grosser solids, such as undisintegrated fæces, paper, etc., should be held back as far as possible, and some effective form of close screening provided, and also provision for the settlement of grit and heavier particles of suspended matter.

The above standards are applicable in the opinion of the Author in any parts of the world where river outfalls are contemplated.

Sea Outfalls.—In discharging a large bulk of sewage into the sea in the proximity of a town, great care is necessary to select a position where the sewage will not be thrown back on to the foreshore, as this is liable to cause a most offensive and, as time wears on, an increasingly dangerous nuisance. A most careful study of the tides should be made, and for this purpose float observations at all states of the tide and prevailing wind and weather should be most carefully taken and considered together. The greatest difficulty occurs during neap tides, when the range of tide is not great and sewage is likely to remain for some hours in the neighbourhood of the outfall. A sea outfall should always be taken out as far as possible from the shore, but never to a less distance than will ensure the sewage being discharged into several feet of water, even at the lowest spring tide. The liquid of the

sewage rapidly becomes diffused in the body of the sea water, but the solid matter may persist for some considerable period, because sea water delays the oxidation of organic matter and it is not until some hours after discharge that purification sets in. Owing to its specific gravity being less than that of sea water, sewage floats on the surface, open to the influence of both tide and wind; and, if carried down to a foreshore, it is liable to cause dangerous deposits. The experiments at the outfall in Bombay shews that the sewage discharged on an ebb tide is carried for a considerable distance along the coast towards the residential part of the island, and is not all broken up by the sea for at least four hours after its discharge from the outfall. In a subsequent chapter this matter will be further referred to and certain float observations explained.

Consideration should be given in a sea outfall to the question of the local fisheries. Fresh sewage discharged into the sea does little harm—in fact, in Bombay, it is popularly believed to have very largely increased the number of fish on the part of the coast concerned. Putrefying sewage is, however, dangerous, and will destroy or drive away fish. Sea birds are great scavengers, and greedily eat all floating matter around an outfall that they can get hold of, but they avoid putrid sewage. Sewage in India may be considered to be fresh until it is six hours old.

The standards mentioned at the end of the paragraphs on River Outfalls cannot be considered as applicable to Sea Outfalls, but none the less, in the Author's opinion, it is desirable to deal with the solids before they are discharged into a Sea Outfall, and very close screening or the provision of sedimentary tanks should generally be provided. The size of tanks must be governed by the rise and fall of the tides and the set of the currents and by the period during which sewage can be safely discharged. In cases where little or no tide exists, as in the Mediterranean, the sewage might probably flow through the tanks continuously to the outfall after depositing the bulk of the grosser solids.

Land Irrigation.—Where neither river nor sea disposal is available, sewage is sometimes deposited on a reserved area of land, in which case the soil is relied on for filtering and oxidising it. Any land is, to a greater or less extent, capable of being used for sewage irrigation, but a sandy calcareous or porous loamy soil is the best. Clay land is not well adapted for this purpose. Suitable land should be laid out in level beds, and the sewage applied in turn to each bed. If a porous stratum of sand or gravel underlies the beds, the liquid will naturally drain away with the subsoil water, but in certain cases it will be found necessary to inseıt underdrains to carry off the liquid. The drains should be laid at a minimum depth of three feet, and in such a manner as to prevent direct vertical percolation into them. Land used for sewage irrigation should be constantly ploughed or turned over to allow of æration, suitably cultivated, and kept free from weeds or anything that would choke the surface of the ground. Porous soil under advantageous circumstances will dispose of 30,000 gallons of sewage per acre per day. The worst soil is probably heavy clay soil, which will not safely dispose of more than 5,000 gallons per acre per day. If possible, sewage should not be discharged on to land without previous treatment in order to remove the solids, as it will rapidly coat the land with a layer of decomposing organic matter, which will hinder the action of the bacteria in the soil and quickly create a nuisance.

Where previous treatment cannot be resorted to, the intermittent application of small quantities of the sewage should be followed in order that the liquid may drain away and the solids be broken up, thus permitting air and oxygen to refill the interstices of the soil. The process is naturally slow, for until air has reached all the interstices of the soil, the purifying action cannot recommence.

The amount of oxygen available varies with different soils and is at the best limited; and further, the underground circula

tion of air is very slight, and without oxygen the ærobic bacteria cannot thrive.

Precipitation.—Under this head is included any system which depends on chemical treatment of the sewage, preparatory to its being discharged to the sea, river, or land, in order to precipitate the solids and deodorise or disinfect the liquid. Such treatment is rarely necessary in the East, where land is generally available for irrigation purposes and the sewage is for the most part what is known as domestic, rather than trade, sewage. A good precipitant must be cheap, and should cause a rapid subsidence of all organic matter in suspension. It should not be actively or cumulatively poisonous, otherwise it would be dangerous to human and animal life. It should have no distinctive colour, as that would arouse sentimental objections; and if a chemically treated effluent is to pass into a stream or be used for the irrigation of crops, the resultant effluent should be neutral or slightly alkaline.

A large variety of processes have been used in Europe, but all are expensive and create a great amount of sludge; and for the reasons given above, it is not proposed to go into them in detail.

Electrolysed Sea Water.—Some years ago, shortly after the outbreak of the first Plague epidemic, when every promising disinfecting system was eagerly considered, an experiment was tried in Bombay of electrolysing sea water and mixing it with the sewage in the sewers so as to destroy organic matter. The system was invented by a Monsieur Hermite, a Frenchman, and has been tried in several places on the Continent and at one or two places in England with a certain measure of success. In this system sea water, or, in default thereof, an aqueous solution of chloride of magnesium and chloride of sodium, is subjected to what is known as "Electrolysis." Under the influence of an electric current the water and the salt are decomposed; and as a result of this decomposition, at the positive pole of the battery, an oxygenated compound of chlorine—very unstable and possessing a

considerable oxidising and consequently disinfecting power—is obtained, while at the negative pole is formed an oxide which has the power of precipitating certain organic substances. The sea water, or its equivalent aqueous solution, when subjected to the action of the electric current as described above, is called electrolysed sea water, and is a good disinfecting liquid. It is practically inodorous, but it is a powerful antiseptic. It destroys microbes, renders suphuretted hydrogen innocuous, and effects a complete sterilization and deodarization of all liquid matter. The installation necessary for this system of disinfection comprises (*a*) a central station containing a dynamo and an electrolysing apparatus, a pump to raise the sea water, and tanks for the storage of the same, unless it can be obtained at all states of the tide, and also tanks for the storage of electrolysed sea water; and (*b*) the provision of a separate system of mains, service-pipes, and domestic fittings for distribution of the fluid in the same way as in the case of ordinary water or gas supply, with branches near the edge of the road to flush the sewer and storm-water drains, or to water the streets with the disinfecting fluid.

The electrolysers are of three sizes: Size A consists of 200 platinum electrodes and 54 zinc disks; B consists of 104 platinum electrodes and 28 zinc disks; and C consists of 44 platinum electrodes and 12 zinc disks. Electrolysers of the first size are useful for industrial requirements. Those of the second are smaller and better adapted to installations on a small scale, such as those for hospitals; and those of the size C are only suitable for still smaller institutions. Several electrolysers can be simultaneously used by connecting them in a series. It is said that the maximum grouping that can be effected advantageously is 10 electrolysers worked by a single dynamo.

The current sent into an electrolyser of type A is generally from 1,000 to 1,200 amperes, of type B from 500 to 600 amperes, and of type C from 250 to 300 amperes. The electro motive force (E. M. F.) required in all cases is from 5 to 6 volts for each electro-

lyser. The dynamo required to give off these currents is similar to that used for electro-plating and other similar purposes, and its distinguishing feature is its capability of producing a large amount of current at a low potential.

The installation fixed in Bombay consisted of two electrolysers capable of producing 1,000 grammes of chlorine per hour, or 440 gallons of electrolysed sea water containing 0·5 grammes* of chlorine per litre. Assuming the dynamo worked for twelve hours a day, the amount of electrolysed sea water produced should be 5,280 gallons. When first started, the installation was worked in connection with a night-soil depot, which disposed of 74 tons of night-soil per day. It was found that 0·5 of a gramme of chlorine was required to disinfect or deodorise one litre of sewage in ten minutes, and therefore 16,576 gallons of electrolysed sea water were required to sterilize the whole of the night-soil of the depot. Much good was done by the use of this electrolysed sea water in lessening the smell of the night-soil depot and no doubt in sterilizing the fæcal matter. An experiment was tried by discharging the fluid straight into the sewer, but the quantity of the fluid produced was not large enough to make any appreciable difference in the large bulk of sewage, which flowed at the rate of 3,500 gallons per minute. The experiment was continued for thirty-four days, during which time 22,000 grammes of chlorine were produced per day, equal to 748,000 grammes or 15 cwts. of total production, at a cost of Rs. 1,039-6-1 or Rs. 1,386 per ton. Unfortunately, however, for financial success, good commercial chloride of lime, containing 30 to 35 per cent. of free chlorine, can be purchased in Bombay for Rs. 260 per ton, which would bring the actual cost of chlorine to Rs. 780 per ton, or little more than half the cost of producing the same amount of chlorine by electrolysing sea water, even without taking into consideration the interest on capital expenditure necessary in the latter case.

* Gramme is a French weight and is equal to 15·432 grains Avoirdupois, Litre is a French measure and is equal to 1·7607 British pints.

The plant was tried for a further period, but with very little difference as regards cost. The fluid was also used in Bombay for flushing gullies and disinfecting privies, but the cost of cartage made the process more expensive than ordinary disinfectants. On account of expense, therefore, this system is only recommended for such places, if any exist, where the price of other good disinfec tants is so exorbitant as to justify it.

Biological Treatment.—Of late years the knowledge of the biological treatment of sewage in Europe has rapidly advanced. The Royal Commission on Sewage Disposal has brought together the experiences of all the greatest Sanitarians in England, and it will almost appear that our knowledge of the subject has now so far advanced as to leave little to be learnt in the treatment of ordinary (as opposed to trade) sewage. It is not proposed to refer at any great length or in detail to this important subject, because there are many standard works written, which deal entirely with the question of Biological Treatment.

The 8th and final Reports of the Royal Commission on Sewage Disposal published in 1913 and 1915 are strongly recommended to students and others interested in the subject.

These reports bring up to date our knowledge on this subject.

Before sewage can be thoroughly purified by a biological process, it must undergo two changes. The solid organic matters must be liquefied and the complex nitrogenous and other organic compounds in the liquid of the sewage split up into their simpler forms, and the whole must then be oxidised. To obtain these changes, sewage must be dealt with first by anærobic and secondly by ærobic bacteria —terms invented and first used by Pasteur. All sewage contains within itself the necessary bacteria for its own purification, and it has been proved that these organisms will quickly grow and multiply in water-carried sewage, rapidly liquefy the solid matters, and finally set up the oxidation of the organic matter, changing it into harmless forms. Mr. Scott Moncrieff claims to be the first to have recognised that organic matter in sewage could be dealt

with by micro-organisms contained in the sewage itself. These organisms are classified into anærobic and ærobic, *i.e.*, those whose work is performed in the absence of free oxygen and those whose very existence depends upon the free access and presence of free oxygen.

The anærobic treatment of the sewage, which produces the liquefaction of the solids, preferably takes place in a tank constructed in such a manner that the velocity of the sewage on entering it is so reduced that the solids are deposited, and that the organisms can thrive in it and liquefy the organic matter during its progress through the tank. For this to be efficiently performed, a tank should be large enough to hold from 8 to 24 hours' supply of crude sewage, according to strength. Such a tank is usually called a "Septic Tank," which is a name given to it by Mr. Donald Cameron, M.Inst.C.E., the late City Engineer for Exeter.

When sewage has undergone anærobic treatment for the specified time, it will be almost wholly without oxygen, that gas having been converted into carbonic acid gas by the decomposing organic matter produced by the mixed organisms which arrive in the tank in the sewage.

The next and second process of purification is performed by the action of the ærobic bacteria which are the organisms that live only in the presence of atmospheric oxygen. These bacteria will work under two conditions, *viz.*, in suitable land, which should contain lime or some other base, or in an artificial filter constructed of some material which will hold air in its interstices. It must be remembered that in all artificial filters we only imitate the process which nature performs for us in land; but in the case of land, however, it is only the first few inches which are usefully employed by the ærobic bacteria, whereas in an artificially constructed filter the whole of the depth can be employed, if the filter is properly constructed. The chemical change made by the filter in the effluent from the liquefying tank is the conversion of the various nitrogenous substances, such as free ammonia, into the harmless compounds of nitrites and nitrates.

The less free ammonia and the more nitrates found in the effluent, the greater the degree of purification. This second change is made with extraordinary quickness—often within ten or fifteen minutes.

Much attention has been given to the question as to whether biological treatment destroys the pathogenic germs that may exist in the sewage, but it appears that there is at present no acknowledged method which enables a bacteriologist to say with certainty that a sewage effluent is without pathogenic germs. However, as it is unlikely that a sewage effluent, in its condition as an effluent, would be used as potable water, this question can be considered as an entirely separate one to that of the purification of the sewage. The question has provoked much argument among bacteriologists, who differ as to whether any or all pathogenic germs are destroyed. The point is an important one, and no doubt before long will be settled; but meantime, it is safer to assume that biological treatment does not destroy pathogenic germs.

EXPERIMENTS AT THE ACWORTH LEPER ASYLUM AT MATUNGA.

Sewage Farm.—Through the kindness of the Chairman of the Acworth Leper Asylum the Author was able for some years to make valuable experiments at the Asylum in regard to sewage disposal. The Asylum lies to the east of the ridge which runs north and south on the harbour side of the Island of Bombay, and is about eight miles from the Fort. It is in such a position as prevents its being drained into the main sewage system of the Island, except by pumping, and it has therefore its own separate system. In the early part of 1901, the Author published a short work, called *Notes on Sewage Disposal*, which dealt with various experiments made by him at the Asylum from the year 1894 up to that time.

It is now proposed to give a brief resume of these experiments, together with some further results. When the Asylum was con-

structed in 1891, it was a part of the Author's duty to supervise the drainage arrangements of the institution. These arrangements consisted of stoneware pipe drains, laid from all nahanis and latrines so as to convey the sullage to two large pits filled with rubble stone and located on the outskirts of the Asylum; but owing to the presence of clay in the subsoil, these pits were unsatisfactory from the beginning and eventually became entirely choked with solid matter, so that the sewage overflowed on to the adjoining land not in the possession of the Asylum. This brought forward complaints from the adjoining land owners, who ultimately gave notice of their intention to apply for an injunction to prevent the Asylum authorities discharging sewage on to their land. This was in 1894, and arrangements were then made to purchase a tract of land adjoining the Asylum on which the sewage matter could be disposed of. Originally, it was thought that it would be sufficient to dispose of the sewage in its crude state on this land, but this was found to be objectionable, as it resulted in a nuisance and in the land becoming coated with organic matter, which destroyed its purifying qualities. The fodder crops grown on the land were unwholesome and cattle would not eat them. It then became necessary to devise some means of purifying the sewage before discharging it on to the land. In 1895, the Author, working independently but curiously enough on the same lines as Mr. Cameron at Exeter, experimentally constructed the open Septic or Liquefying Tank shewn in Plate 44 and described more in detail later in this Chapter. It should be mentioned, however, that at this time the name "Septic Tank" had not been coined, nor had the properties and possibilities of such a tank been even approximately ascertained.

The land was at this time laid out as a small experimental Sewage Farm, in plots averaging about half an acre in area and so arranged as to be irrigated by the effluent from the Liquefying Tank. The channels or carriers for conveying the effluent were lined with half stoneware pipes of 9 inches and 6 inches diameter

according to requirements. In 1895 the area was 3·63 acres, but with the extension of the Asylum, this has now been increased to 5·92 acres.

The natural soil of the Farm was of the least desirable character for cultivation purposes, being yellow clay overlying muram but by much ploughing, turning over, and irrigation it has been greatly improved, although still leaving very much to be desired. The level of the land on the Farm is such that only one-third of it can be irrigated by gravitation direct from the Liquefying Tank. For irrigation of the remainder, the sewage effluent is allowed to flow into wells, from which it is lifted by Persian wheels, bullocks being used as the motive power. During the dry weather, the whole of the daily sewage from the Asylum—upwards of 20,000 gallons—is discharged into the Liquefying Tank and afterwards disposed of on the Farm ; but during the monsoon months, in periods of heavy rain, when water is not wanted for the crops, the effluent is allowed to flow away with the storm-water to the sea, it being then inoffensive and practically innocuous.

The crops chiefly grown on the Farm are guinea grass, maize, and jowar, with a rotation crop of some pulse or vegetable. Lucerne has been tried, but not with any very great success, the reason being that the plant obtains its nitrogen from the air by means of tubercles which settle on its roots. If the tubercles do not exist in the soil, the plant will not grow. English vegetables have been grown with considerable success, all attaining a large size. Six crops of maize and jowar are obtained in a year and a cutting of guinea grass once every month throughout the year.

The following figures represent the total returns of fodder grown on the Farm for the year 1904-05 :—

Maize	.. ..	37·54 tons.
Guinea Grass	.. ..	36·71 ,,
Jowar	.. ..	132·97 ,,
Vegetables	.. ..	0·56 ,,
Mangel Wurzel	.. ..	1·91 ,,
Lucerne	.. ..	3·91 ,,
	Total ..	213·60 tons.

As only 5 acres, on an average, were under cultivation during this year, this gives a total return of nearly 44 tons of fodder per acre for the year—a result which must be considered as very satisfactory. Nearly all this fodder has been supplied at market rates to the Health Officer of the City of Bombay for feeding the Health Department bullocks.

The labour on the Farm, except the supervising staff, consists to a large extent of lepers, who are paid a fair wage for the work they do. Their health is very greatly improved by the regular exercise thus obtained but their strength is never equal to that of a healthy cooly.

The financial success of the Farm has been a progressive one. In 1899-1900 the net profit was equal to 21·92 per cent. on the capital outlay; while in 1900-1901 it reached 30 per cent. and in 1904-1905 45 per cent.

The following tabulation shews the progressive gross revenue and expenditure from 1895, when the Farm was first started, to 1905. Except for the first year, the Farm has always paid its way, and it furnishes an excellent example of the improvement that will take place in the fertility of poor land after some years of irrigation with sewage effluent:—

	Income.			Expenditure.		
	Rs.	a.	p.	Rs.	a.	p.
1895	158	7	10	509	12	1
1896	1,011	12	6	520	13	10
1897	1,722	2	1	570	8	6
1898	1,556	2	6	611	5	0
1899	3,781	12	9	1,057	10	5
1900	5,167	11	1	2,371	14	5
1901	7,073	6	11	3,972	8	0
1902	9,584	6	11	3,991	6	0
1903	6,978	3	0	3,830	12	0
1904	8,625	3	0	3,207	9	11
1905	8,513	9	10	3,464	6	8

During the eleven years that the Farm has been under irrigation, none of the plots have remained fallow for more than one month at a time. During 1901, some of the crops shewed signs of failing, and arrangements were then made to burn stable litter upon the

ground spread to a depth of 1 foot, the ashes being dug in. This resulted in re-supplying the land with potash and phosphates and the necessary chemical bases, and since then quite abnormal crops have been obtained. This is the only sign of failure that has been observed during the time the Farm has been in existence.

Considerable doubt existed as to whether the irrigation of sugarcane by sewage effluent was likely to prove injurious to the plant, and the point has from time to time been freely discussed at Poona and elsewhere. Accordingly, in April 1901, a careful experiment was carried out, about 200 cuttings of sugarcane being planted in a small plot on the Farm. The trial was made with cane of the variety known in the Bombay Market as *Surti*. The plot was irrigated solely with the effluent from the "Liquefying Tank," four or five times a month, for a period of nine months, no manure of any other kind being applied to it. The crop was good, and the outturn, when it was cut on the 27th January 1902, was 500 canes. This figure, however, does not represent the actual number of canes, for rats appeared to have taken a great liking to them, and, in spite of all precautions, at least 100 canes must have been destroyed by the time the crop was ready for cutting.

The juice was extracted in the ordinary way by crushing the canes between wooden rollers. It was at once boiled and converted into jaggery or "goor" by a man engaged in that particular trade, who was specially brought to the place for the work.

The total quantity of jaggery obtained was 3½ maunds. It was of a brown colour with a very sweet taste and crystallized and solidified properly.

A sample of the raw sugar was forwarded to Dr. J. Walter Leather, Agricultural Chemist to the Government of India, and the following is the analysis of it with his remarks :—

Cane-sugar	69·80
Glucose	13·65
Moisture and dirt	16·55
	100·00

"The sample contained a good deal of dirt, which might with advantage "have been screened from the juice before boiling. Otherwise it is a good raw "sugar and better than much which is commonly made by the cultivator."

(Sd.) J. WALTER LEATHER.

The result shews that sugarcane can be successfully grown under effluent irrigation and that the quality is at any rate as good as that ordinarily grown by the cultivators with the aid of the usual solid manures. This expeiiment should be an encouragement to continue the growth of sugarcane in larger quantities under similar circumstances.

Mangel Wurzels were tried on the Farm during 1904 with some success, but the crop had a tendency to run to excessive leaf. This is also the experience with English vegetables. An interesting analysis was made by Dr. J. Walter Leather, in January 1905, of two samples of maize grown entirely with sewage effluent irrigation at the Sewage Farm. They were specially examined for the presence of a Glucoside named Bhurrim, sometimes met with in maize. The maize was declared to be quite free of any such noxious ingredient and was of a specially good quality for fodder purposes. Since the above was written at the end of 1905 the Author is informed that the efficiency of the farm has always been maintained and the profit from crops equally so, but that the experiments which are described hereafter were not continued afteı the Author left India for Egypt in 1906.

Liquefying Tank.—Plate 45 shews the installation of the open Liquefying Tank at Matunga, consisting of a series of four tanks, each 20 feet by 10 feet by 4 feet deep, connected with the other by an opening 12 inches wide in the dividing wall of the tank at the same level as the inlet to No. 1 tank. Each tank is further divided by a baffle wall for three-fourths of its length, which almost makes two compartments of it, round which the sewage flows. Each tank is fitted with a loosely adjusted scum board to reduce the surface velocity of the sewage. Any tank can be cut off from

the others by means of wooden stops and closed for cleaning purposes. The whole of the four tanks working together have a total capacity of 3,020 cubic feet of 18,875 gallons, though, as deposit increases, this capacity correspondingly decreases. The surface sewage, when the tanks are fairly free of deposit, takes an average of eight hours to pass through the distance of 160 feet or at a velocity of 20 feet per hour. This average result was obtained by several float experiments after removing all the scum boards.

The velocity of sewage through a Liquefying Tank varies with the volume of sewage flowing into it, which is not a constant quantity, and it again varies as the capacity of the tank is reduced by deposit. The surface velocity must not be taken as the average velocity for the whole tank, as the ratio between the surface and average velocities varies according to the design of the Tank and the amount of deposit. Parallel to the Liquefying Tank and running the whole length is a sludge tank, connected to each compartment by means of a 9-inch pipe. The bottom of this sludge tank is two feet below the level of the bottom of the Liquefying Tank. When it is desired to clean any of the compartments of the Liquefying Tank it is shut off from the others by closing the necessary stops in the channel; and the sewage and sludge are run into the low-level sludge tank through the 9-inch pipe connections. The sludge is then allowed to settle the liquid being drawn off by a pump, and when the sludge has dried, it is removed and dug into the land, which it seems to considerably benefit for although the dry sludge has no value as manure it helps to lighten the soil. The sludge tank is only used—when it becomes necessary to clean out any of the compartments—at intervals of about three years.

The Asylum has been slightly enlarged since the Liquefying Tank was constructed, and upwards of 20,000 gallons of sewage are now passed through it per day and dealt with satisfactorily. The liquefaction of the solid matter in the sewage discharged into

the tanks is very complete, and over 80 per cent. of reduction in albuminoid ammonia is attained during the time the sewage is passing through them.

The population of the Asylum is now about 430, and the whole of the sewage finds its way by a regular system of pipes from the washing places, latrines, and dhobi-ground to the Liquefying Tank, except a small quantity intercepted for experiment in a Ducat Filter. In the light of the present experience, the design of the tank is defective; and if it were necessary to now reconstruct it or to construct another, an altogether different design would be adopted and more suitable walls constructed with openings alternately at the top and the bottom. These tanks, however, have done the work required of them quite efficiently, and considering that they were constructed in the first instance purely for experiment in a then unknown direction, their success has been remarkable. A series of observations of the temperature of the air and of the sewage entering and leaving the tanks, taken over a period of nine months, shews that there is no difference in the temperature of the sewage entering or leaving the tanks and that the temperature of the sewage has no connection with the temperature of the outside air.

The following is the average of several analyses of the crude sewage at Matunga and of the effluent from the Liquefying Tank, made by the late Dr. C. H. Cayley, M.A., M.D., D.Ph., who was Divisional Health Officer, Bombay:—

Parts per 100,000.

	Total Solids.	Suspended Solids.	Chlorine.	Free Ammonia.	Albuminoid Ammonia.
Crude Sewage ..	64·91	31·83	3·36	1·08	1·62
Tank Effluent ..	30·96	8·80	3·35	1·11	0·311

This gives on an average a purification of the sewage equal to 81 per cent. as estimated on the albuminoid ammonia.

In the first eleven years the tank was working, it was cleaned out on three occasions only, the first cleaning being after three years' use. It was calculated that up to that time the organic matter liquefied in the tank amounted to 61 tons. In England, it is usually calculated that 50 per cent. of the solid matter deposited in a Liquefying Tank is disposed of; but the experience at Matunga is that at least 75 per cent. is liquefied.

The Author is indebted to Dr. J. Walter Leather, the Agricultural Chemist to the Government of India, for the following analysis of a portion of the solid matter removed in 1902 from the tank at the time of cleaning:—

"*Analysis made on 18th February,* 1902.

Moisture	65·18
Organic matter	9·74
Mineral matter	25·08
Total ..	100·00
Containing nitrogen	·56
,, sand..	13·08
,, phosphoric acid	0·32

"This material appears to correspond closely in composition to that which Dr. Rideal examined from the Exeter Septic Tank."

(Sd.) WALTER LEATHER,
Agricultural Chemist to the Government of India.

This is an interesting analysis, and it will be noted that 72 per cent. of the solid matter, or humus as it is called, remaining in the tanks at the time of cleaning was mineral matter and there fore not further reducible by the bacteria. In average fæces the percentage of organic matter is 86 and mineral 14.

The inference to be drawn from the above is that an even warm temperature as much to do with the proportion of organic matter disposed of and left undisposed of, respectively, by the bacteria; for whereas 24 hours are stated to be required in England for the treatment of the sewage in Liquefying Tanks, the same work is more efficiently done in Bombay in 8 hours, with a purely domestic sewage.

When it is necessary to clean out a Liquefying Tank, care should be taken to always leave a small amount of deposit in the bottom for the immediate renewal of liquefying action when the tank is put into operation again. The bacteria will no doubt develop in an absolutely clean tank, but it will take time for them to accumulate to the quantity requisite for the maximum degree of purification.

Too much stress cannot be laid on the fact that the surface or scum of the Liquefying Tank should not be disturbed, as interference with bacteria means a suspension of their work.

The following analyses of sewage taken at the point of discharge from No. 2 into No. 3 tank (see Plate 45) and of the final discharge from the tank four hours afterwards are very interesting, for the result shews that probably the greater part of the breaking down of the organic matter is done by the bacteria in No. 1 and No. 2 tanks, which is further borne out by the fact that in some respects the effluent from No. 4 tank is inferior to that from No. 2 tank—

Parts per 100,000.

	Total Solids.	Suspended Solids.	Chlorine.	Free Ammonia.	Alb. Ammonia.
Crude sewage entering Liquefying Tank, 21st February, 1901	64	16	4·00	2·64	·68
Sewage taken from point of discharge of No. 2 Tank, 10th May, 1901	44	16	2·3	1·60	·448
Effluent taken from final discharge of Liquefying Tank, 10th May, 1901	36	8	2·3	1·44	·608

The analysis of the crude sewage is given as a guide only, it having been made on a different date from that of the effluents, and is, as indicated by the chlorine, not of the same sewage. The point that it is desired to bring out is that, at any rate in India,

the largest percentage of purification is carried out much more quickly than is generally supposed.

It has been proved by experiments in England that no purification advantage accrues from allowing sewage to remain in a Liquefying Tank for more than 24 hours and that it is far from being improved by remaining 48 hours.

The analyses made from time to time of the effluents taken from the different compartments of the Liquefying Tank at Matunga, after 4 hours, 6 hours, and 8 hours contact, respectively, go to shew that the maximum purification is obtained in a warm climate in much less time than in a climate such as that of England.

The average temperature of sewage in England is between 51° and 58° F., while in Bombay it is between 78° and 90° F.

From an average of analyses spread over two years, the Author has found that with a temperature of sewage at 83·60° F., 55% of the purification occurs in 4 hours, 82% in 6 hours, and 84% in 8 hours. It may, therefore, be assumed that, with a climate similar to that of Bombay, an 8 hours contact with ordinary domestic sewage will give a purification that will be satisfactory.

A word here may not be out of place in regard to the relative advantages of covered and uncovered Liquefying Tanks.

The word "covered" denotes that the tank is completely roofed. Two compartments of the Liquefying Tank at Matunga are now covered for the purpose of generating and collecting the gas. Observations shew that with an air-tight roof on a Liquefying Tank, if the gas is not removed as it forms, purification is interfered with. Thus at Matunga, when only No. 1 compartment was covered, much of the purification which took place in that tank before it was covered was transferred to No. 2, and the same process is at present taking place in regard to No. 3, now that No. 2 is covered.

The opinion of the Author is that unless it is desired to make use of the generated gas, it is better to allow a tank to remain

uncovered; for, if a tank is scientifically constructed, no nuisance will arise from it after it has come into fair working condition.

Sewage that has been passed through a properly designed Liquefying Tank is so free from organic matter that, if it is subsequently dealt with by æration only, it rapidly becomes clear and free from smell.

In regard to the designing of a Liquefying Tank, it is desirable to point out that the size of a tank should always be calculated on the maximum flow of the sewage. It should, if possible, be three times as long as it is broad, and its depth should not exceed 6 feet, 5 feet being a preferable depth. The first object of a Liquefying Tank is to reduce the flow of sewage so that all solid matter may be deposited as quickly as possible. The position and construction therefore of baffle walls is a matter of considerable importance. It is very questionable whether the submerged inlet serves the useful purpose it is supposed to, for there is certainly less disturbance of the tank when the inlet is at the surface. However, no hard and fast rule can be laid down in this matter, as so much depends on the installation.

In small installations, the great difficulty is always the uncertain flow of sewage. It is therefore desirable to make a Liquefying Tank for a small installation sufficiently large to counteract this difficulty.

Plate 46 shews a sketch for a proposed open Liquefying Tank for the sewerage of Ahmedabad. The tank is designed to deal with 1,200,000 gallons of sewage per diem. It consists of six compartments, two of which are each 200 feet long by 25 feet wide by 5 feet deep and the remaining four 150 feet long by 25 feet wide. The discharge of each tank is at the same level over a weir.

Plate 47 shews a covered Liquefying Tank suitable for a small installation. Here the compartments are 11 feet long by 6 feet wide by 5 feet deep, and the passage through the tank is alternately at the top and the bottom of the different partition walls. The

roof is constructed of some light gauge galvanized iron and fixed on angle iron ribs with a manhole at one end for inspection purposes. The withdrawal of the gas from this tank might be at any convenient point by means of a pipe let into the roof.

Plate 48 shews a Liquefying Tank with a filter attached—an installation which was designed for the purification of the sewage of a large bungalow in Bombay. This installation has been working for a considerable time satisfactorily. Here it will be noticed that the roof of the tank has been provided with an opening covered with wire gauze, as it was not intended to make any use of the gas. The description of this class of filter will be dealt with later in the Chapter. Plate 49 shews a drawing of a covered Liquefying Tank.

Filters.—Various filters have been constructed at Matunga combined with the liquefying and other tanks, and fitted with different arrangements for distributing sewage on to their surfaces, and also with several different materials as filtering media. Experiments have been tried with a Liquefying Tank combined with Aerobic Filters, and with a Liquefying Tank combined with a Contact Filter, and with a Macerating Tank combined with Colonel Ducat's Filters.

A Stoddart Filter with a patent "distributor" combined with a Macerating Tank and a Colonel Ducat's Side Aerated Filter dealing with crude sewage only have also been tried. More recently a series of two contact beds fitted with Adam's Timed Siphons have been erected to deal with the Liquefying Tank effluent, as also a Streaming Filter fitted with an Adam's Rotating Distributor.

All these filters, tanks, and modes of distribution of sewage on to filters, many of which are new and interesting, are fully described and commented upon in the following pages.

Attached to the Liquefying Tank, shewn in Plate 50, are two small Aerobic Filters, 2 feet 6 inches by 2 feet 6 inches by 2 feet 6 inches, built entirely for experimental purposes. These filters are designed to receive and to purify the effluent from the Liquefy-

ing Tank at the rate of 250 gallons per square yard per day. The medium used for filtering is in one case burnt brick, broken from 1-8th inch to 1-inch cube, and in the other, English coal also broken to the same sizes.

In the brick filter, the effluent from the Tank is delivered by three galvanised distributing pipes under a head of 7 inches and having 1-16th inch perforations at intervals of 5 inches. These distributing pipes work fairly well, in spite of the fact that some of the perforations are occasionally closed by floating solid matter. In the coal filter the Tank effluent is distributed by small tipping troughs, which, when full, tip automatically one way and empty their contents on to the filters. This kind of distribution is apt to disturb and ridge the top of the filtering medium, especially if it is of fine material. The time of the passage of the effluent through both filters is exactly the same, being from 10 to 12 minutes and the resultant effluent shews a very high degree of purification, and is in appearance like the purest spring water—bright, clear and free from all deposit and smell.

The following are the two analyses of the effluents from each filter made by the late Dr. C. H. Cayley in February 1901 and in July 1902 :—

Parts per 100,000.

Filter.	Total Solids.	Chlorine.	Free Ammonia.	Alb. Ammonia.	Nitrites.	Nitrates.
Burnt brick effluent taken February 1901	29·33	3·63	0·340	0·106	0·343	3·84
Burnt brick effluent taken July 1902 ..	32·85	2·7	0·024	0·042	*Nil.*	11·70
English coal effluent taken February 1901	20·00	3·20	0·172	0·065	0·201	6·35
English coal effluent taken July 1902 ..	22·85	2·4	0·010	0·207	Trace.	2·214

The analyses are interesting and shew that the efficiency of each filter has been quite maintained during the eighteen months that had elapsed since the first analyses were made.

They have been continuously worked without cleaning or being in any way interfered with since their construction in January 1901. The percentage of purification over the crude sewage admitted to the Liquefying Tank is over 90 per cent., and the time taken in the operation is eight hours in the Liquefying Tank and twelve minutes in the filters.

Dr. Cayley remarks in regard to the two later analyses that "the effluents were clear and bright with a small trace of a brownish sediment" and that "the sewage was weak." This latter may be accounted for by the fact that either the sewage was night sewage, which is always weaker than day sewage, or that there had been rain during the night, which diluted the sewage flowing into the Liquefying Tank for although the Asylum is drained on the "separate" system, some rain water gets into the sewers through the washing places. Such a high degree of purification as is shewn by the above analyse is not necessary for an effluent of sewage farming in India, and the amount of purification obtained from a scientifically constructed Liquefying Tank without further filtering is all that is required as the land converts the organic matters into those which are necessary for the life of plants, and very quickly does what the filters would do, leaving the effluent in such a degree of purity that it may with safety be allowed to flow where it will.

Neither of the two materials used in these filters for filtering purposes has degraded to any large extent, nor has any choking of the filters ensued. Of the two materials, English coal gives the better result and this has also been noticed in England, but no satisfactory explanation has been forthcoming.

Fig. 36 shews a small filter for upward filtration designed by the late Mr.W.Santo Crimp, M.Inst.C.E., and called a "Macerating Tank." Sewage is admitted at the bottom of the tank and passes

upward through a layer of one foot or more of road metal. The solid matter is retained in the bottom and is no doubt there disposed of by anærobic bacteria as in a Liquefying Tank. When cleaning is necessary, the sewage is passed through the road metal or filtering material the reverse way, and the deposit flushed out through a sluice provided for this purpose. This class of tank is useful chiefly for arresting the solids in the sewage, but its purifying properties are slight, as it is constructed of a small size, compared with a Liquefying Tank.

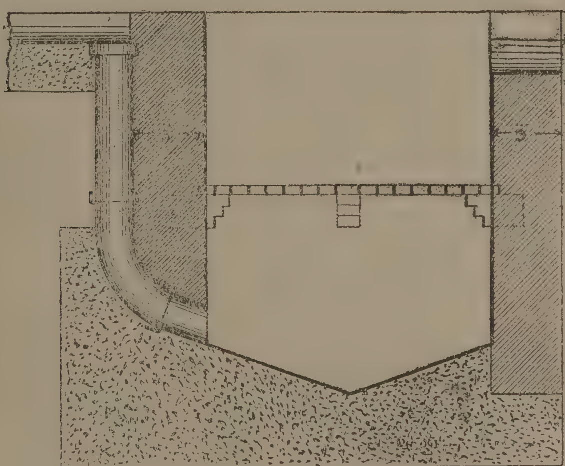


FIG. 36.

Adjoining the Macerating Tank, and combined with it, is a filter 6 feet by 3 feet by 3 feet deep, shewn in Fig. 37 worked on the principle of a Contact Filter. This filter receives sewage after it has passed through the Macerating Tank, so that it arrives free of solid matter to a large extent. The filtering medium used is coal clinker all broken evenly to one inch cube. Originally, three inches of river sand at the bottom was tried, but this was found to be useless as it was gradually all washed out with the effluent.

This filter is worked in cycles of eight hours, that is to say, it is filled in two hours, rests full for two hours, is emptied in two hours and rests empty for two hours. Sewage at the rate of 250 gallons per square yard per day is passed on to the filter, and analyses shew that the purification obtained is 80 per cent. or about the same as with the Liquefying Tank. This must be considered satisfactory, as the sewage, which has had practically no previous purification, is only in actual contact with the filtering material for an average of four hours. In England, filters of this

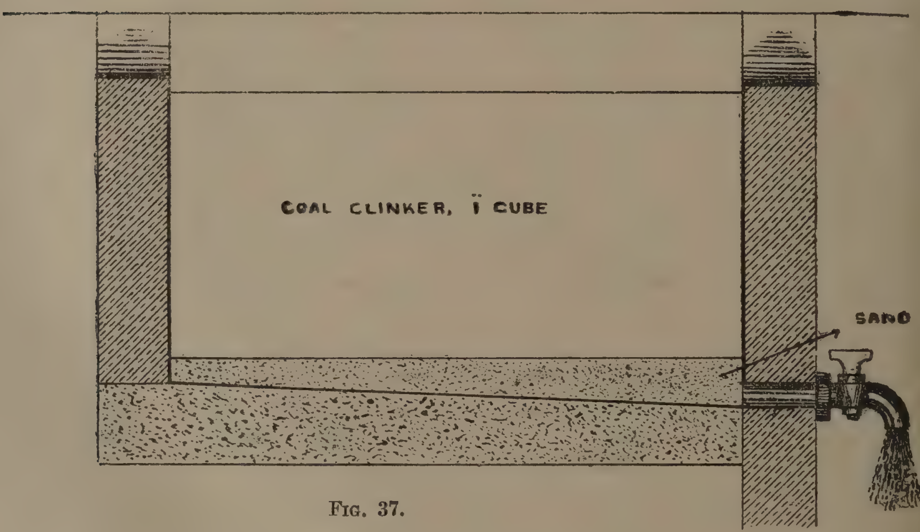


FIG. 37.

description are frequently built in a series of two so as to provide for two contacts, and sometimes three contacts are considered to be necessary to obtain a satisfactory degree of purification.

When the filter was constructed in October 1899, its sewage capacity after careful measurement was found to be 41 per cent. of its total cubical capacity. It was again measured some two months afterwards and found to have been reduced to 33 per cent. In July 1902, that is 31 months later, all the contents of the tank were removed, measured, washed, and put back again, and it was

found that the capacity had been further reduced to 31 per cent. or by 2 per cent. only in 31 months, and there was no degradation of the clinker filtering material. This is a very interesting result, because one of the apparently insurmountable difficulties with this class of filter in England at present is the rapidity with which it sludges up, and the cost of constantly cleaning such a filter of large area is a very serious item in the expense of a biological installation. There is no doubt that the Macerating Tank which retained the greater part of the solids in suspension helped largely to the good result obtained at Matunga, and it goes to shew that this kind of filter can be worked without serious sludging up for a considerable period, if, in some way, the greater part of the solids in the sewage are arrested and not passed on to the filter. If the degree of purification attained after passage through this filter were insufficient under any particular circumstances, the additional purification desired could be attained by further filtration through a second or even a third similar filter.

Combined also with the filter above described is a small covered Liquefying Tank, constructed of lime concrete, the internal dimensions of which are 5 feet by 4 feet by 3 feet. This Liquefying Tank is worked under similar conditions to the open Liquefying Tank and supplies the Contact Filter with effluent alternately with the Macerating Tank. It was worked continuously for eighteen months (July 1902), and the results obtained are on a par with those of the open Liquefying Tank, the analysis shewing a purification of 81 per cent. This result agrees with the experiments made with covered and open Liquefying Tanks in England.

Three continuous Aerobic Filters on Colonel Ducat's principle have been erected at Matunga. For descriptive purposes these filters are numbered 1, 2, and 3, the first having been working continuously from two to six years and the latter two working for three years up to 1902. The special feature of a Ducat's Filter are (1) the side aeration; by which air is passed into the body of the filter for the supposed better development of the

aerobic bacteria, and (2) the direct reception of crude sewage without any previous treatment.

Plate 51 gives a drawing of No. 1 Filter, which is 5 feet by 5 feet by 8 feet deep or nearly three square yards in area, which, at 250 gallons of sewage per square yard, is capable of dealing with 750 gallons per day. The filter is supplied with sewage obtained from a bathing place and a latrine, used only by a colony of eighteen sweepers attached to the Asylum. Early in 1902, a water meter was fixed on the supply pipe, which shewed that the sweepers were using 40 gallons of water per head per day or 720 gallons in all, so that the filter was then getting its full complement of sewage. The water-supply has since then been reduced to 10 gallons per head per day and the comparative analyses of the effluents will be given later on.

The side aeration of this filter is much less than arranged for in Colonel Ducat's Standard Absaf Filter, where the walls are honeycombed with pipes. At alternate heights of one foot, pipes with butt joints are laid crossways through the filter, the joints of the pipes being about $\frac{3}{4}$ inch apart and meeting the pipes in the wall to enable the outside air to pass freely into the centre of the filter.

The filtering medium used is "overburnt brick," broken from $\frac{1}{8}$ inch to 1 inch cube, the smallest being at the top. This material is too fine for a filter dealing with crude sewage only; and though the ultimate results have been satisfactory, it is advisable to always have the top layer, at any rate, of coarser material, so that the solid excreta, etc., may be the sooner disposed of and also that the sewage discharged on to the filter may not "head up," as has here been the case on several occasions. The sewage is discharged on to the filter by means of tipping troughs as shewn in Plate 51.

These tipping troughs are automatic, and are balanced and hung in grooves, which require to be kept well lubricated. They tip alternate ways and empty as soon as they fill by overbalancing. They are satisfactory, except for the objection before stated, that

with fine filtering material as a top layer they ridge that material in front of the discharge from the tippers.

The filter has, during the six years of its existence, given uniformly satisfactory results. Only three times during that period has the top foot of the filtering material been removed and washed. It was then found by measurement that the degradation of the burnt brick had amounted to 50 per cent. of its original bulk; and this is an undoubted defect in this class of filtering material.

The following analyses of crude sewage and of the effluent taken in December 1900 and in July 1902 shew the purification obtained in the 45 minutes which the sewage takes to travel through the filter:—

Parts per 100,000

	Total Solids.	Susp. Solids	Chlorine.	Free Ammonia.	Alb. Ammonia	Nitrites.	Nitrates.
Crude Sewage, December 1900	380·67	310·67	5·73	2·531	1·253	*Nil.*	*Nil.*
Effluent, December 1900, 240 gallons per square yard ..	54·67	*Nil.*	5·367	0·077	0·067	0·625	13·555
Effluent, July 1902, 60 gallons per square yard	·85	*Nil.*	3·85	0·064	0·034	Trace.	28·8

The effluent in both cases was exceedingly bright and clear and free from any smell, and shewed that a very large amount of purification had taken place and that there was also very little free ammonia, practically the whole of the nitrogenous matter having been purified into nitrates.

That the filter has maintained its purification properties the July effluent undoubtedly shews.

The experiments made at Leeds under the supervision of the Royal Commission on Sewage Disposal prove that side aeration is not necessary in a Continuous Filter, provided the surface

of the material is kept open and clean, and that there is practically no difference in the purification obtained in an aerated and a non-aerated filter. Such aeration is always from the top, the air naturally following the sewage into the filter. As an example of the bacterial efficiency of this filter, it may be stated that a large dead rat was placed in the filter on one occasion and covered with about one inch of filtering material, and when examined four days afterwards, the whole of the rat had been broken up by the bacteria and had disappeared, leaving but a few fragments.

The success of this filter has been quite phenomenal. In the light of present knowledge, the filter has been, so far as its filtering medium is concerned, wrongly constructed, that is to say, the upper layer of the material is fine while it should have been coarse, and the lower part is coarse while it should have been fine. Again, nothing but crude sewage is discharged on to the filter, and on any morning lumps of excreta can be seen on its surface. Yet, with those disadvantages, the average of the analyses for absorbed oxygen taken every week for nearly twelve months gives 0·16 per 100,000 parts. The absorbed oxygen has never exceeded during that time 0·23, and on one occasion it dropped as low as 0·05 per 100,000 parts.

The effluent has been uniformly bright and sparkling, in a way that no other filter at Matunga has ever attained.

The filter has now been working for more than six years without intermission; and beyond the occasional removal of the first foot of the filtering material; nothing has been done to it during that time.

Filters Nos. 2 and 3 have been constructed alongside each other as shown in Plate 52, and each measures 5 feet by 3 feet by 5 feet in depth, or 3 feet less in depth than the minimum recommended by Colonel Ducat. The sewage supplied to them is obtained from a latrine and a bathing place, erected solely for the use of one of the wards containing 24 adults.

It first passes through a small Macerating Tank, 2 feet by 2 feet by 3 feet in depth, and is then discharged on to the filters. The filtering medium used in No. 2 filter is burnt brick broken into from $\frac{1}{2}$ inch to $\frac{1}{4}$ inch cubes, and that in No. 3 is English coal broken to the same size. For months, the effluents from both filters were turbid and cloudy, but in time they gradually cleared and were then for some months uniformly bright and clear. These two filters were in continual use for nearly three years, and the result shews that the depth of the filter of Colonel Ducat's design may quite well be less than the eight feet stipulated by him, and that with only five feet of filtering material a very satisfactory effluent can also be obtained. It must be noted, however, in regard to these two filters that sewage is first passed through a Macerating Tank, where most of the solids in suspension are arrested, though no particular purification takes place.

The following analyses made by the late Dr. Cayley in July 1902 shews that the quality of the effluents is exceedingly good: a comparison with No. 1 filter can hardly be fair, as that receives crude sewage:—

Parts per 100,000.

	Total Solids.	Chlorine.	Free Ammonia.	Alb. Ammonia.	Nitrites.	Nitrates.
No. 2 Filter, Brick ..	65·7	4·64	0·077	0·124	*Nil.*	31·00
No. 3 Filter, Coal ..	70·0	4·86	0·009	0 045	*Nil.*	39·857

Both effluents were bright and clear and free from any smell and deposit. It will be noticed that the results obtained from the coal-filtering medium is again superior to that from the brick, the sewage in each case being the same and supplied at the same time.

Two samples of effluents taken on 10th March 1901 and kept in stoppered bottles until July 1902, retained their clearness and brightness without smell of any kind shewing that the purification was complete and that there was no secondary putrefaction.

The results obtained at Matunga with Colonel Ducat's filters have been uniformly good; but in any installations built in the neighbourhood of dwellings, it is desirable to give the sewage some previous treatment, for the reasons that an open filter receiving crude sewage must always be slightly offensive, as fæcal matter is likely to lie on the surface for some hours before being entirely broken up. Matunga has been more fortunate with a Ducat Filter than Leeds, where the discharge of crude manufacturing sewage on to a similar filter was found to be a distinct failure though, when worked with a Liquefying Tank effluent, the result was more favourable. Temperature and the class of sewage are probably responsible for the better result here. For England Colonel Ducat has specified that the sewage should be heated before being delivered into the filter, but that process whatever its advantage may be in England is certainly not necessary in India.

After the experiments carried out with Continuous Filters in England, side aeration cannot be considered a necessary or even a desirable feature in a filter, therefore that special peculiarity of the Ducat filter may be dismissed. Again, the two filters above described show as already pointed out, that Colonel Ducat's minimum depth of eight feet is more than is necessary. This is very important as a loss of eight feet in head is far more often impossible to afford without pumping than that of five feet. The 8-foot filter has undoubtedly purified crude sewage very satisfactorily, but probably in India any Continuous Filter scientifically constructed would do the same.

Early in 1902 it became necessary to make arrangement for the drainage of a large Sanitorium in an unsewered district in Bombay and the arrangement shewn in Plate 53 was carried out. The installation provides for all the sewage of the establishment being

brought to a point and discharged into two Macerating Tanks, each 10 feet square and 4 feet deep. The tanks are placed side by side, so that they can be worked together or alternately, one being in use, while the other is being cleaned or kept in reserve. The lowest point of each Macerating Tank is connected by means of a sluice and a 9-inch pipe to a sludge tank for cleaning purposes. The sewage from the Sanitarium flows in at the bottom of the Macerating Tank and filters upwards through fourteen inches of road metal, the level of which is raised slightly higher than the weir connection with the open drain which leads to the filter, thus avoiding room for the growth of mosquitoes in the standing sewage. The filters are three in number and are constructed in a similar manner to Colonel Ducat's Absaf Filter. Each of them is 25 feet by 8 feet by 6 feet in depth : the sides are of concrete, honey-combed with 3-inch stoneware pipes, spaced about 3 inches apart: the outer ends of these pipes are at a higher level than the inner, the slope being to guard against the fluid passing out from the sides of the filter. Longitudinal and lateral pipes with open joints run right through the filter for the promotion of aeration, and these are spaced about 2 feet 4 inches apart horizontally and 1 foot 5 inches vertically.

The filtering material is entirely clinker, varying from $\frac{3}{4}$ inch at the top to $\frac{1}{2}$ inch at the bottom. The sewage is discharged on to tipping troughs from open channels running at right angles to them. The troughs are of the same kind as those described for the Ducat Filters at Matunga and are fixed 1 foot 9 inches apart from centre to centre, each trough running the full width of the filter, and the sides of each trough are 3 inches apart at the top.

The installation is designed to completely dispose of the solid and fluid matter from 36 water-closets, the sullage from 50 *nahanis* and all the waste water from the kitchens. The effluent from the filters discharges into an ornamental tank surrounded by ferns in which gold fish thrive, and the effluent can be used without

any offensive smell for gardening purposes. The Sanitorium was constructed to accommodate 200 people, but that number has been often largely exceeded.

This installation is in a residential part of the town, and the Sanitorium is almost always fully occupied.

The following analyses of the crude sewage and of the effluent made by the late Dr. Cayley shew how exceedingly satisfactory the purification is :—

	Crude Sewage.	Effluent.	Proportion.
Free Ammonia	17·32	0·2	Parts per million.
Alb. Ammonia	5·44	0·28	Do.
Chlorine	3·2	4·9	Grains per gallon.
Total solids	59·00	47·0	Do.
Dissolved solids..	36·00	..	Do.
Suspended solids	23·00	..	Do.
Nitrites	*Nil.*	·126	Parts per 100,000.
Nitrates	*Nil.*	4·5	Do.

"A very good effluent. Most of the organic matter has been converted into nitrates."

The effluent for this analysis was taken 35 minutes after the crude sewage, but it is evident that the effluent is one of a stronger sewage. The result is eminently satisfactory, and with the experience gained at Matunga there is no reason to suppose that the installation will not always continue to work well.

Up to the end of 1905 the installation has given universally good results. Analyses made from time to time shew that the absorbed oxygen varies little from 0·20 per 100,000, which is an exceedingly good result. Occasionally, the Macerating Tank has been cleaned, but not oftener than once in six months. This is undoubtedly the disadvantage of the installation and the Author

cannot recommend such a combination. A Liquefying Tank takes more room, but purification is done with little or no nuisance to the neighbourhood, while with a Macerating Tank there soon comes a time when it is overcharged with organic matter and a nuisance results, and there is a further nuisance when all the materials of the tank have to be removed for cleaning purposes. The filters have always been satisfactory, but the construction of the Macerating Tank has been an undoubted defect in the installation.

Continuous Filter fitted with Stoddart's Distributors.—Adjoining the two 5-foot Ducat Filters shewn on Plate 54 and sharing the same sewage with them, has been erected another filter, 5 feet by 5 feet by 4 feet deep. The special feature of this filter is its "Distributor," which was first designed by Mr. F. Wallis Stoddart, F.I.C., F.C.S., Public Analyst for Bristol; but in other ways it is just an ordinary continuous filter with closed sides. It is not a filter on to which it would be satisfactory to discharge crude sewage: such sewage should either be closely screened or passed through some previous treatment before it could with success be applied to a "Stoddart's Distributor." Several of these filters have been working near Bristol for a considerable time with, it is stated, quite satisfactory results.

Plate 54 shews the patent "Distributor;" it is made of thin galvanized iron and consists of a number of narrow gutters arranged at right angles to the supply channel, and rests upon its margin and upon a suitable support at the other end. The level of the "Distributor" is so arranged that the sewage from the channel flows equally into all the gutters. In these gutters there are a series of holes in which nails are loosely inserted. Besides these nail-holes, slots are cut in the top of the corrugations of the gutters. The sewage fills the gutters until it overflows through the slots, and, passing along the undersides, drips continuously from the nail points on to the filter, like rain.

The "Distributors" are made in sections, 8 feet long by 1 foot 6 inches in width, and are placed about 9 inches apart on the filters and 3 inches above the filtering medium.

The "Distributors" work by gravitation and require no head. This filter has closed sides and the filtering medium is burnt brick, broken to $\frac{3}{4}$ inch cube. It is combined with a Macerating Tank as are the Ducat Filters Nos. 2 and 3, and it has been working more or less continuously for twelve months, but still the effluent has been turbid and unsatisfactory.

The following is the analysis of an effluent made by the late Dr. Cayley in July 1902, when the filter had been in use for twelve months :—

Parts per 100,000.

	Total Solids.	Chlorine.	Free Ammonia.	Alb. Ammonia.	Nitrites.	Nitrates.
Stoddart's Filter ..	57·1	4·57	1·15	0·56	·736	1·77

Dr. Cayley says :—" The effluent was thick, dirty-looking, and " had a bad smell. There was a considerable amount of suspended " organic matter, *i.e.*, unconverted sewage, equalling 9 grs. per " gallon. The free ammonia was enormously high, the figures " above being only approximate, as the amount was too great to " allow of a proper test. Very little nitrification has taken place. " This is a very bad effluent. This effluent was evidently in a " high state of putrefaction and continued to decompose after " 24 hours in a bottle."

There is therefore little real purification in this effluent, a reduction of the solids being apparently all that has so far been achieved.

Another analysis made by Dr. Cayley, on 2nd October, 1912, shews very little improvement on the previous one. In this

instance, crude sewage as well as the effluent from the filter was analysed :—

	Crude Sewage.	Effluent.	Proportion.
Free Ammonia	10·640	13·320	Parts per million.
Alb. Ammonia	5·2	3·540	Do.
Chlorine	3·3	3·4	Grains per gallon.
Total Solids	74	38	Do.
Dissolved Solids	32	..	Do.
Suspended Solids	15	..	Do.
Nitrites	*Nil.*	Trace.	Parts per 100,000.
Nitrates	*Nil.*	0·9	Do.

"A very poor effluent, containing some solid fæcal matter, as wel as being thick and having a strong smell."

There is little improvement in the effluent during the three months interval between the two analyses ; and, besides the reasons previously given, it is possible that the less depth of the filtering material—this filter being only 4 feet in depth and the Ducat's Filter alongside being 5 feet—had something to do with the continuous indifferent results obtained.

It is also more than probable in a filter receiving sewage, as this does, that the covering up with plates of a considerable area of the surface of the material and the delivery of the sewage from the nails on to exactly the same spot day by day, may have some thing to do with the poor results obtained. Whatever may be the reason, the fact remains that after fifteen months' trial the effluent leaving the filter is still in a putrefactive condition.

It will be kept in view that the sewage supplied to the two 5-foot Ducat Filters and the Stoddart's Filter was exactly the same, being supplied from the same channel with branches to the different filters.

With the high temperature in India, a filter should be in full working order in a month, provided the sewage has some previous anaerobic treatment; but if sewage is only screened or passed through a Macerating Tank, the probability is that it will be some months before it gives a satisfactory effluent.

An interesting experiment was made with the Stoddart and Ducat Filters by removing the Stoddart D stributors from the former and placing them on the latter, and removing the tippers from the latter and placing them on the former. This experiment resulted in an almost immediate improvement in the Stoddart Filter effluent and a corresponding decrease of purification in the Ducat Filter effluent, which had been previously universally bright for many months and almost immediately commenced to shew signs of opalescence.

On the 26th of October, 1902, Mr. G. Midgley Taylor, M.I.C.E., F.C.S., made an estimate of the oxygen absorbed by the sewage entering the Ducat and Stoddart Filters, and by the effluent discharged from each of them, with the following results:—

Parts per 100,000.

Crude sewage	.. 1·12,	oxygen absorbed in 4 hours.
Effluent from the Stoddart Filter	.. 0·70	,, ,, ,, ,,
,, ,, Ducat Filter	.. 0·12	,, ,, ,, ,,

This confirms the strong probability previously mentioned that the covering of the surface of the filter, built with closed sides, with plates, of the description of a Stoddart Distributor, is deleterious to the working of the filter, and tends to prevent air passing into the filter from the surface, which is a necessity in a filter of this description. The previous analysis of the effluent of the Stoddart Filter made by Dr. Cayley shewed that effluent to be in an advanced state of putrefaction: the latter result therefore is a great improvement in purification.

The above results with a Stoddart's Filter are not as satisfactory as they should be. In 1903, the Author had the pleasure of meeting

Mr. Stoddart at Bristol and also the opportunity of inspecting his filters at Horfield, and certainly the results obtained there were at that time very much in advance of anything obtained at Matunga. Having this in view, the Author decided early in 1904 to construct a new Stoddart's Filter on somewhat different lines.

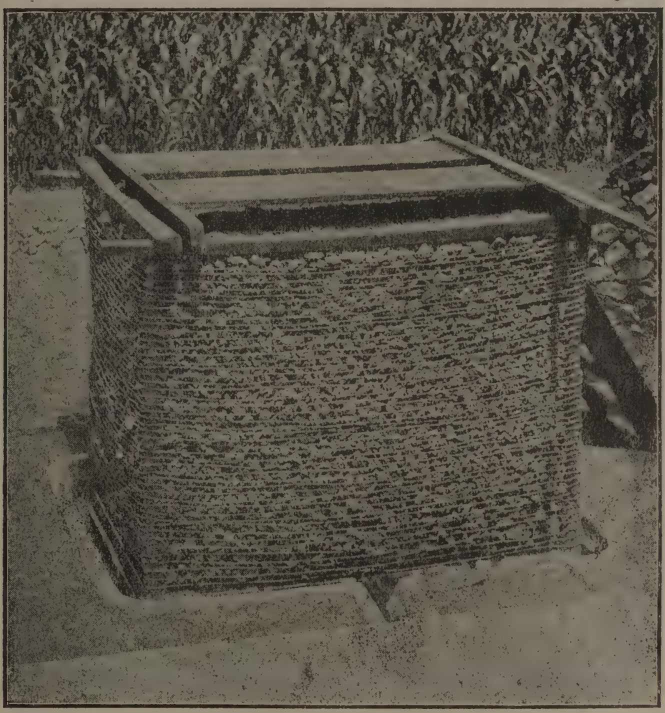


FIG. 38.

A filter was therefore constructed 7 feet by 6 feet by 6 feet deep. A photograph of this is shewn in Fig. 38. The filter is constructed on a sloped concrete base with four posts built into the concrete at the corners and the whole surrounded by wire to support the filtering medium, which in this instance is coal clinker of the best quality, carefully washed before being placed in position.

The effluent from the Liquefying Tank is pumped direct to the Stoddart Distributors. Regular weekly analyses for absorbed oxygen, taken from July 1904 to August 1905, shew that at an average temperature of 81° F., the absorbed oxygen was 0·326 per 100,000 parts, while that for the effluent from the Liquefying Tank was 0·921.

After the first week, the analysis shewed that the absorbed oxygen in four hours per 100,000 parts was 0·57. After seven weeks' working, this dropped down to 0·30, which was a fairly satisfactory result. This result was maintained with slight variations both ways until the end of August 1905. The effluent takes about fifteen minutes to run through the filter and the average percentage of purification obtained in that time is 65. There is little doubt that a Stoddart Filter built under the conditions shewn in the above photograph should be success ful, and nothing can be more simple and economical in construction.

The filter has required practically no attention and has shewn no signs of deterioration.

In September 1902, the Author constructed at Matunga, a circular filter, which is called a "Streaming Filter." The sides of this filter are constructed of dry brick supported at four places by dry rubble stone buttresses. The filter is 12 feet in diameter by 7 feet in height. The filtering medium is coal clinker, of uneven size from 2 to 3 inches. Effluent from the Liquefying Tank distributed on to the filter by one of Adams' Patent "Rotating Distributors."

This distributor consists of a bucket rotating on ball bearings and fitted with radial arms of ¾-inch galvanized pipes perforated with holes every five inches. These holes are made only on one side of the pipe and in opposite directions to one another, the pressure of the water on the sides opposite to the holes forcing the arms to revolve. The apparatus can be worked with two or more arms according to the flow of sewage.

The radial arms depend for their velocity upon the head of liquid and angle of delivery; and by depressing the arms the number of revolutions can be increased.

If it is desired to sluice the filter out, the arms should be depressed and the flow of sewage increased to such an extent that in a short time the filter is cleansed of its solid matter. This is a very satisfactory way of cleansing the filter and is obviously more economical than removing all the material and washing it.

The amount of material remaining in the filter is, however, small, as filters worked on this principle eject a certain amount of the solid matters along with the effluent. The solid matters thus ejected are quite innocuous and readily settle, leaving the liquid effluent brilliant and clear.

The Liquefying Tank effluent takes about fifteen minutes to pass through the filter: the radial arms thoroughly distribute it over the surface of the filter, and the discharge at the bottom is equal at all points.

The following are the three analysis, made in 1902, by Dr. Cayley, of the Crude Sewage, the effluent from the Liquefying Tank, and the effluent from the Streaming Filter, the latter being after the Streaming Filter had been in work for a fortnight. This Dr. Cayley describes as having a slight milky appearance, faint brownish tinge, trace of sediment, and slight earthy smell:—

	Crude Sewage.	Effluent from Liquefying Tank.	Effluent from Streaming Filter.	Proportion.
Free Ammonia	11·300	9·408	3·040	Parts per million.
Alb. Ammonia	26·450	2·520	1·480	Do.
Total Solids	102·00	23·00	18·00	Grains per gallon.
Suspended Solids	53·00	3·00	..	Do.
Chlorine	3·6	2·4	2·1	Do.
Nitrites as NO_2	..	..	1·314	Parts per 100,000
Nitrates—				
as N	..	..	0·35	
as NO_3	..	..	1·55	

This effluent, although the Streaming Filter had then worked for only fifteen days, is nearly as good as that obtained from the Double Contact Beds, hereinafter described.

That the effluent has improved since the analysis was made by Dr. Cayley there is no doubt. It is much clearer in appearance, and an estimation made by Mr. G. Midgley Taylor, M.I.C.E., F.C.S., of the oxygen absorbed in four hours, on the 26th October, 1902—twelve days after the analysis made by Dr. Cayley—shews it to be a first class effluent. A sample of the Liquefying Tank effluent taken from the radial arms, and fifteen minutes afterwards a sample of the effluent from the filter, gave the following results :—

Parts per 100,000.

Liquefying Tank effluent	0·59	Oxygen absorbed in 4 hours.
Streaming Filter effluent	0·07	

Taking into consideration the fact that the Streaming Filter had been then in use for only about a month, the above results cannot be considered otherwise than exceedingly satisfactory.

Since the above date, the filter has continued to work for several hours every day and is still (1906) working.

Regular weekly analyses have been taken for absorbed oxygen, and the result has been uniformly good. The highest record of the absorbed oxygen was 0·34 per 100,000 parts and the lowest was 0·07, while the average for a period of one year was 0·21—a satisfactory result. Liquefying Tank effluent at the rate of 440 gallons per square yard per diem, equal to nearly 2,000,000 gallons per acre, is passed through this filter.

The filter is very simple in construction and has required no kind of attention. The rotating distributors work easily under a head of one foot six inches. Beyond the fact that the ball bearings require to be lubricated and the orifices in the arms to be ocassionally cleansed, the apparatus needs no particular supervision, and undoubtedly this class of filter has a great future before it.

Contact Beds.—Contact beds are so called because sewage remains in them in contact with the filtering material for some

length of time. As is described hereinafter in this Chapter, the effluent from the Liquefying Tank at Matunga flows by gravitation from a raised iron tank on to a series of two contact beds through a 2-inch pipe.

Before discharging on to No. 1 bed, the effluent from the Liquefying Tank is discharged into a measuring tank as shewn on Plate 55. This measuring tank holds, when full, 2,500 gallons of effluent —the exact quantity required to fill each contact bed in turn, and has a recorder which registers its discharges. It is fitted with a siphon, which automatically discharges the contents of the tank when the latter is full.

The size of each contact bed is 30 feet by 17 feet by 3 feet 4 inches of useful depth. In each bed a small chamber is partitioned off at the outlet side of the bed by three masonry walls in which an Adams' Automatic Timed Siphon is placed. The over-draw arm of the siphon goes through one of the partition walls and dips into the liquid contents of the bed, the inlet to the arm being protected by a perforated half-round galvanized iron sheet. A small bent pipe is placed at the side of the siphon, one end dipping into the small chamber and the other into the liquid contents of the bed. When the latter is full, the pipe begins to lead the effluent from the bed into the small chamber, the rate of flow being regulated by a stop-tap fixed on the pipe in the chamber. When the chamber is filled to a certain height, the siphonic action comes into play, discharging the whole of the contents of No. 1 bed into No. 2. The duration of contact thus depends on the time the chamber takes to be filled to the requisite height, which is, as stated above, regulated by the stop-tap. The same procedure then takes place in the No. 2 bed as in the No. 1, the final discharge from it being into an open channel communicating with the main channel, which empties itself into two of the wells on the sewage farm. The filtering medium used in both the beds is coal clinker, that in No. 1 being broken to pass through a screen with 1-inch meshes and that in No. 2 through one with $\frac{3}{4}$-inch meshes.

The following has been the cycle in vogue for the filling and the emptying of the contact beds during 24 hours : No. 1 contact bed commences its contact at 9 A.M. each morning, and remaining so until 11 A.M., when it automatically discharges into No. 2 bed—a proceeding which takes exactly 30 minutes. No. 2 bed is then in contact until 1-30 P.M., and is finally emptied by 2 P.M., both beds then remain empty until 5 P.M., when No. 1 fills again and is in contact until 7 P.M. It then automatically discharges into No. 2 bed, and the same procedure as in the morning takes place, No. 2 bed being finally emptied at 10 P.M., after which both the beds remain empty until 9 A.M., the next morning, so that in the 24 hours each bed rests empty for 5½ hours after the first contact and 13½ hours after the second contact.

The contact beds commenced working with the effluent from the Liquefying Tank on the 15th of September, 1902, from which date until the end of the month they received one filling a day; and from 1st October and onwards they received two fillings a day, as described above.

On the 13th and 14th of October, 1902, Dr. Cayley made the following analyses : A sample of crude sewage entering the Liquefying Tank at 8 A.M., on 13th October was taken by removing a certain quantity of sewage every ten minutes until a bucket was filled : the sewage was then stirred and mixed, and a bottle removed for analysis. Dr. Cayley describes the sample as "thick, dirty yellow ; considerable quantity of fæcal sediment ; offensive smell."

	Crude Sewage.	Effluent from Liquefying Tank.	Effluent from No. 1 Contact Bed.	Effluent from No. 2 Contact Bed.	Proportion.
Free Ammonia ..	11·200	9·408	4·704	2·640	Parts per million.
Alb. Ammonia ..	26·450	2·520	1·740	1·180	
Total Solids ..	102·00	23·00	16·00	15·00	Grains per gallon.
Suspended Solids ..	53·00	3·00	..	..	
Chlorine	3·6	2·4	2·1	2·05	
Nitrites as NO_2 ..	..	..	..	0·115	Parts per 100,000.
Nitrates					
as N..	..	..	..	0·5	
as NO_3	..	..	..	2·214	

During the fortnight succeeding the 15th of October, 1902, a very striking improvement was noticed in the effluents from both the contact beds. This was undoubtedly due to the fact that the beds were getting into good working order and also to the increase in the temperature of the sewage. An estimate of oxygen absorbed in four hours, made by Dr. D. A. Turkhad, M.B., C.M. (Edin.), on the 18th October 1902, of the effluent of the 2nd Contact Bed gave a result of 1·35 of absorbed oxygen in parts per 100,000. A similar estimation made on the 25th October following, also by Dr. D. A. Turkhad, gave a result of 0·42, shewing a large increase of purification in the week's working. On the 26th of October, 1902, an estimate, made by Mr. G. Midgley Taylor, M.I.C.E., F.C.S., of the effluent of the same contact bed gave 0·28 of oxygen absorbed in four hours in parts per 100,000.

These figures shew that after only six weeks' working a result is obtained equal to any in Europe, even after passing through a series of three contacts.

About the middle of June, 1904, that is to say, nearly twenty-one months after the beds were started, an experiment was made by shortening the time of the contact to only one hour in each bed ; but the result of the weekly analysis was unsatisfactory, and after working the beds for two months with the lessened contact, the original arrangement was restored.

The contact beds were started in October, 1902, and they have been worked daily for just under three years, during which time the silting up has been very gradual, indeed. At the end of August, 1905, it was found by careful observations that No. 1 bed had silted up to the extent of 25 per cent. of its water capacity, and No. 2 to a considerably less extent. For three years working this must be considered a satisfactory result. It remains to be seen how long the beds will take to right themselves, for from the 1st September, 1905, neither of them has been in operation, but on refilling the beds on the 15th February, 1906, it was found that

they had thoroughly cleared themselves and were again in perfect working condition.

The average of analyses for absorbed oxygen, taken weekly for about eighteen months, gives the effluent from the 1st Contact Bed as 0·46 per 100,000 parts, while for that from the 2nd Contact Bed as 0·29.

Of all the combinations above described, there is little doubt that a Liquefying Tank, combined with a continuous filter, gives the purest effluent and an effluent which is in many ways actually better than much of the water considered to be potable in India. But the process under this combination is a comparatively long one, even in the climate of India, as it takes between eight and nine hours to be complete.

The combination of the Macerating Tank and the 5-foot Ducat Filter has been very successful at Matunga, the process taking only some twenty-five minutes, that is, five minutes through the Macerating Tank and twenty minutes through the filter; but it has the drawback, and it is rather a serious one, of not giving a satisfactory effluent ordinarily until some months after it has started. It is doubtful whether a Ducat Filter by itself dealing with crude sewage should be recommended for use in a large way. It has been eminently successful at Matunga, dealing only with pure domestic sewage, but for use on a large scale some previous treatment of the sewage is desirable for the reasons already given.

As pointed out, land in India is generally available for sewage farming, and nothing more than treatment of the sewage in a Liquefying Tank is therefore necessary. Such a purified sewage as is obtained from the combinations described, is not worth the expense necessary to obtain it, and the extra purification gives no special advantage over the Liquefying Tank effluent when it is to be applied to the irrigation of crops. Effluent from the various combinations has been several times tried upon the crops at Matunga, but the result was not commensurate with the expense of building the filters.

Of all the "Distributors," probably some form of a circular sprinkler gives the best results. All tipping troughs have the fault of ridging fine filtering material. The orifices in fixed pipes are liable to choke, but this disadvantage is not so noticeable in rotating arms, the Adams' type of which has given satisfaction at Matunga.

The best filtering medium used at Matunga has been coal clinker. "Over-burnt brick," after being in use for some months degrades badly, and so to a lesser extent does English coal; but if clinker is carefully picked, there will be no degradation for years. Probably the best material is coke, but its cost is somewhat prohibitive.

The Author has had the opportunity of reading the able and interesting paper by Major Ernest Roberts, I.M.S., published in "Scientific Memoirs by Medical Officers of the Army of India," Part XII, 1801; but the limits of this chapter only admit of a very brief reference to it.

The biological deductions recorded by Major Roberts are not altogether in agreement with those ascertained in Bombay. Major Roberts has laid considerable stress on the necessity of providing three distinct stages for the purification of sewage: First, anaerobic through a Liquefying Tank, either closed or open, or by upward filtration on the Scott-Moncrieff plan; secondly, intermittent downward filtration; and thirdly, filtration through porous arable land. He also states that it is undesirable to depend solely on downward filtration, and recommends a combined Scott-Moncrieff and Intermittent Downward Filter for Cantonments.

The experiments at Matunga have now lasted for over ten years, and though the sewage is in quantity only some 20,000 gallons per day, still the opportunities for observing biological results have been greater than elsewhere in India. Further, although the sewage flowing into the Liquefying Tank is only of average strength, that supplied to the Ducat Filter is stronger and equal to 10 gallons per head.

One of the prominent proofs afforded at Matunga is that an eight hours' purification in a Liquefying Tank and a subsequent fifteen minutes passage through an Aerobic Filter (*i.e.*, two processes) are sufficient to give a very high purification result. Also that sewage passed through a Macerating Tank, which is an improvement on a Scott-Moncrieff Upward Filtration bed, does not give immediately satisfactory results, as has been shewn earlier in this chapter in regard to the 5-foot Ducat and the Stoddart Filters.

Major Roberts states that the "Dibdin" Ducat, and Absaf "processes are entirely unsuited to the concentrated sewage of "Cantonments and of Natives, even with the most extravagant "preliminary dilution with water."

The reverse has been the experience at Matunga, where an 8-foot Ducat Filter, dealing with crude sewage derived from a colony of sweepers, has been working continuously for five years. The amount of water (originally 40 gallons per head and now only 10 gallons per head) supplied with the sewage to the filter is measured by meter, so that the extent of dilution is not open to question, and the success of the filter has not been exceeded in any installation that the Author has seen. There has been no appreciable choking in the body of the filter, neither was there any trouble at the start, as in about six weeks it was in good working order.

As already stated, of all the combinations that have been discussed in the foregoing pages, the Author considers that a Liquefying Tank combined with a Continuous Aerobic Filter, will give the greatest satisfaction. A Liquefying Tank should be constructed to give a contact of eight hours in a climate, where the temperature does not fall below 55° F. In districts where the temperature falls to freezing point and even below it, the tank should be constructed to hold from 12 to 24 hours' supply of sewage.

A satisfactory depth for an Aerobic Filter is 7 feet. If that depth can be attained, success is assured. The filtering material

should be either coke or coal clinker, any other filtering material though suitable in other respects, being apt to degrade in time. The size of filtering material should range between 3 inches as a maximum and 2 inches as a minimum.

The most economical construction of a filter is shewn in Plate 56. Wire is easily obtainable nearly everywhere and it is also cheap. Undoubtedly, the success of the recent Stoddart Filter at Matunga is largely due to its open sides, for although open sides are not a necessity in cases where air can freely penetrate the filter from the top, yet with closed distributors, such as Stoddart's, the Author is of opinion that open sides are preferable.

The Author makes no apology for repeating the record of the experiments made at Matunga during a series of twelve years, in the Second Edition, because the work was almost entirely original and even in the light of 1915 knowledge, it contains useful information.

DESCRIPTION OF HYDROLYTIC TANK AND OXYDISING BEDS.

The Author is indebted to Dr. Owen Travis, Barrister-at-Law, and Mr. Edwin Ault (since deceased) for the interesting account of their Hydrolytic Tank and Oxydising Bed. Briefly they advocate the abolition of the Liquifying Tank and would merely pass sewage through a settling tank at just sufficient velocity to deposit the organic matter. The sewage is then passed on to Oxydising Beds (filters) and it is claimed that the process not only takes a much shorter period, but also gives a better purifying result than the present method of Liquefying Tank treatment and continuous filtration.

Plate 57 illustrates the Hydrolytic Tank, which is divided into two parts.

The first part consists of two "Sedimentary Chambers," laterally situated, and a central "Liquefying Chamber."

The sewage, having first passed through a "Detritus Tank," enters the Sedimentary Chambers and traversing their length

emerges therefrom over weirs *aa.* as indicated by the arrows. The time thus occupied (about five hours) suffices for the deposition of the suspended solids of the sewage. The deposited matters gravitate through openings *bb.* at the bottom of the dividing walls of the chambers, and are accompanied with, and accelerated by, a proportion of the liquid being allowed to flow into and through the Liquefying Chamber. The section of the latter chamber, below the level of the openings *bb.* provides for the reception and accumulation of the deposited sludge pending its hydrolysis; the section of the chamber above the openings *bb.* provides for the flow of the liquid and for the carrying away of the gaseous and liquid products, due to the hydrolysis of the deposited matters; the time occupied by the liquid in passing through the Liquefying Chamber being about fifteen hours. The relative flow of the liquid through the Sedimentary and Liquefying Chambers, both as regards velocity and quantity, is regulated by the relative capacities of the chambers and the widths of the respective weirs.

When the sludge has been sufficiently hydrolised, or when its level approaches that of the openings *bb.* the valves *cc.* are successively opened and the lowest portion of sludge, that most digested, is forced through the sludge pipe *d.* by the head of the liquid in the tank.

The effluents from the Sedimentary and Liquefying Chambers, and such finely divided or light sedimentary matters as may be carried therewith, overflowing the weirs, drop into and become intimately mixed in the channel *c.*

The second part of the Hydrolytic Tank, to which the liquid now passes, consists of a series of "Upward Anaerobic Filters" filled with flint stones or other material of suitable size. The mixed effluent is deflected to the bottom of the first filter, as indicated by arrows, and passes upwards through the material (leaving the suspended matter adhering thereto) and overflowing the dividing weir is again deflected to the bottom of the second filter, passes through the material of the second (and third or more filters) and

finally issues from the tank at *f.* occupying during its progress through the second portion of the tank about three hours.

Should there be any accumulation of sludge in this part of the tank, provision is made for its withdrawal in a manner similar to that described in connection with the Liquefying Chamber.

The Hydrolytic Tank is, as a whole, covered in, and the gases and volatile products generated therein are continuously and systematically exhausted by means of a fan in order to keep the gas tension within the tank and that of the contained liquid, at as low a pressure as practicable, so as, on the one hand, to avoid the possibility of any explosion, and on the other to obviate some of the difficulties incidental to the objectionable odours and to the subsequent treatment of the effluent.

From the Hydrolytic Tank, the effluent is taken to "Oxidising Beds" on to which the liquid is delivered intermittently by means of a syphon arrangement. The liquid is collected in syphon chambers of such a capacity that each is filled, in not less than say ten minutes, and when full the contents are discharged automatically by means of the syphon *g.* on to the upper or nitrifying Layer of the beds and percolating through, falls on to and through two or more nitrifying layers fixed underneath, the final effluent being drawn off by the Channel *h.*

The even distribution of the liquid on to the upper layer is secured by having the syphon *g.* of such a discharging capacity as to deliver the liquid with a rapidity sufficient to flood a bed, the surface of the latter being protected from disturbance by perforated tiles, wire netting, or other device. The liquid capacity of the nitrifying layer should be about equal to that of one discharge from the syphon Chamber, and the layer itself should be formed of coarse sand or other suitable material of such grade as to allow of one charge of liquid to completely percolate through before the next is ready.

The nitrifying layers should be formed of coarse gravel or other suitable material of such grade as to provide convenient space

for the growth of the nitrifying organisms, so that the phagocytic action and the dependent organismal filtration may be developed to the fullest extent, and at the same time that provision be made for efficient aeration.

The successive layers of the oxidising Beds are separated from each other by spaces through which a current of air is drawn by a fan, and through which the liquid falls from one layer to the other, thus providing the necessary oxygen for the life work of the organisms and a means of conveying away the gasses produced thereby.

By admitting the air to the beds through a pipe or conduit, the volume can be controlled and also the air can be heated in order that, during severe weather, the best conditions may be established for the maximum activity of the organism.

Since the appearance of the pamphlet containing the foregoing interesting matter, Dr. W. Owen Travis has carried out a large number of systematic examinations on the action taking place in the various sections of the Hydrolytic Tank, which go to shew that besides the bacterial action so thoroughly examined by the Massachusetts Board of Health, there is an important physical process occurring, which would account for the clogging up of "bacteria beds" probably to a greater extent than the passage of matters in suspension.

It had been observed that contact beds not only clogged at the surface but right through the whole depth of the beds, and it has been difficult to account for this clogging by the action only of suspended matter. Dr. Travis found that a clean effluent from the first part of the Hydrolytic Tank still deposited a much larger volume of solid matter in the second part of the tank than was represented by the solids in suspension passing thereto. He even found that if the effluent from the first part were filtered, so that no solids were in suspension, the filtrate coming into contact with walls, plates, or stones, for example, continued to deposit solid matter. These solids were evidently in an unstable soluble form, in what has been designated a colloidal state or an emulsion, which, on being

brought into contact with solid surfaces, have their physical unstable equilibrium disturbed and become separated into more stable solid and liquid forms. In contact beds the solids so separated have no doubt contributed largely to the clogging of their whole depth.

The result of these examinations has been the entire remodelling of the second part of the Hydrolytic Tanks. A series of thin plates, at a slight angle from the vertical, are placed at small distances from each other, for the double purpose of presenting a large contact surface for the effluent from the first part of the tank to impinge against, and to allow of the solid matters gravitating down to the floor of the beds. The flow of the liquid is from the bottom upwards, and a space is formed below the bottom edges of the plates for the accumulation of the sludge, when it is drawn off in a manner similar to that in the first part of the tank.

The result of the entire operation is an effluent very greatly superior to any hitherto procured, as can be seen from the following table of comparative results :—

	Liquid capacity.	Solids in suspension remaining in the effluent.	Percentage reduction in albuminoid nitrogen.
1*st*—"Continuous undisturbed Sedimentation" Septic Tank—			
London County Council's Fourth Report, 1902	6 hours	50·5%	Not stated
Hydrolytic Tank (1st portion) ..	6 ,,	2·0%	57·7
2*nd*—Septic Tank (Average results) ..	24 ,,	30·0%	44·0
Hydrolytic Tank	12 ,,	1·0%	64·8
3*rd*—Experimental Septic Tank—			
Massachusetts State Board of Health's Thirty-Fourth Annual Report, 1902 (220 gallons)	22 ,,	46·1%	40·0
Model Hydrolytic Tank (300 gallons per day)..	12 ,,	1·0%	77 6

The sewage flowing over the weirs of the first portion enters the second portion of the tank. The latter consists of three hydrolising chambers, which are arranged in sequence. The sewage passes to the bottom of the first chamber by a descending channel, rises slowly in the chamber and flows over a weir, enters the descending channel of the second hydrolising chamber, rises upwards through that chamber, and repeats the operation in the third chamber.

Each chamber—with the exception of a clear space above for the flow of the liquid controlled by a submerged wall (built to keep back a small amount of floating matter) and a space below for the accumulation of sludge, from which it can be withdrawn—is occupied by thin plates separated by 4″ spaces, through which the liquid passes. Plates so arranged attract particles to them, which accumulate until their weight exceeds the power of attraction, when they slip from the plates and fall into the sludge space below. This accumulation is, in the main, confined to the upper surface of the plates, and the gases, freely generated, escape and pass upwards along the under surface of the plates. The analogy between the first and second portions of the tank can now be seen. In the first or hydrolytic portion, the gases generated in the sludge space are prevented from interfering with the settling solids by the walls of the liquefying chamber, and in the second portion or hydrolising chambers, each plate separates the ascending gases on the under surface from the deposited solids on the upper surface. These experiments have indisputably shewn that the hydrolising chambers, when fitted with plates in the manner described, are immeasurably superior in working than chambers fitted with broken stone, etc., as hitherto used.

Since the above was written six Hydrolytic Tanks have been built in connection with the Cairo Main Drainage disposal works at the sewage farm Gebel el Asfar. These tanks are capable of dealing with 50,000 cubic metres of sewage, or the whole of the dry weather flow, in 24 hours. Each tank contains two sedimentation chambers having submerged inlets controlled by penstocks.

The sewage after travelling the whole length of the tank passes out at the end over two weirs, the length of each being equal to 40 per cent. of the total weir length of the tank, so that a flow of 10 per cent. is supplied downwards, and helps to carry any settled solids into the liquefying chamber. This chamber is V-shaped, and the floor is divided into six sludge chambers, each separated by a low dwarf wall and provided at the lowest point with a sludge draw off fitted with a plug controlled by long spindles. The sewage enters this chamber through the openings provided at the spring level of the arch, and emerges at the end over a weir, the discharge length of which is equal to 20 per cent. of the total output of the tank. A more detailed account of these tanks appears under the description of the Disposal Works, Cairo Main Drainage, and it is sufficient to say that the anticipations of the inventors of the tank have been fully justified in so far as this installation is concerned, and the Author is more than satisfied with the purification qualities of the tanks.

There is another tank so similar to the Hydrolytic Tank that it probably owed its inception to that tank. It is known as the Emscher Tank, and was invented by Mr. I. Imhoff, the engineer to the Emscher Rivers Board.

This tank however differs from the other, inasmuch as the sludge chamber bears a larger proportion to the settling chamber than is the case in the Hydrolytic Tank, and consequently the sludge has a longer time to rot and to consolidate. Also no portion of the sewage actually flows through the sludge chamber and the effluent is likely to be freer from suspended solids and from smell.

Several of these tanks have been built in England, and some more are projected. It is stated that they are quite satisfactory for the purpose intended.

One of the worst forms of sewage that the Sanitary Engineer has to deal with, and one that is often met with in India, is undoubtedly that from tanneries. It is usually composed of

spent lime and other chemicals, highly charged with organic matters, both of animal and vegetable origin. Sewage of such composition as this cannot be treated biologically; it can only be satisfactorily dealt with either by chemical treatment or by passing it through precipitating tanks, after first cleaning out floating matter such as hair, etc., and afterwards largely diluting it with fresh water and discharging it either into the sea or a river. The usual method of treating tannery sewage in England is to add Sulphate of Alumina, which can be cheaply purchased under the trade name of Alumino-ferric.

The chemical effect of the addition of alumino-ferric to tannery sewage, which is strongly alkaline owing to the lime used in the tanning process, is to produce a dense precipitate, which in settling carries down solid matters and also certain portions of dissolved organic matter, at the same time removing a large proportion of the colour from the effluent. The effluent, however, from the tank is even after being chemically treated, of a foul and offensive nature. All tannery sewage, before entering the precipitating tank, should be efficiently screened through screens with spaces not more than $\frac{1}{2}$ inch wide. The bars of these screens should be rectangular in shape, the screens themselves sloping at an angle of 45°, a hand rail being provided at the top to enable the raking of the screens to be easily and safely effected. A scum board should also be placed across the tank to catch any floating substances that evade the screen. All screenings and surface floating matter removed from the tanks should be burnt. The solid matters retained in the precipitation tanks will require to be removed from time to time, and the best means of doing this is by employing a chain pump.

It is desirable in case of all tanneries that arrangements should be made to compel each owner to treat the sewage of his own tannery before it leaves the premises.

CHAPTER VII

Modern Methods of Sludge Disposal

THE following is a ıeprint, with trifling emendations, of a paper submitted by Dr. Gilbert Fowler, D.Sc., F.I.C., Consulting Chemist to the Manchester Corporation Rivers Committee. Lecturer in Bacteriological University of Manchester, England, to the Fifteenth International Congress of Hygiene and Demography held in Washington in 1912, and summarises the progress made in the science of sewage purification up to that time.

The scientific solution of the sewage problem will not be attained until the following results can be guaranteed for any given case :—

1. An effluent which will not deteriorate the stream into which it flows.
2. No nuisance in the course of sludge disposal.
3. No nuisance from smell or from flies in connection with the filter beds.
4. An expenditure strictly proportionate to the sanitary and esthetic results achieved.

Those of widest experience will be the least ready to say that these criteria of success are at all commonly fulfilled.

It may not be uninstructive briefly to consider these four directions of effort, with the object of seeing what has been satisfactorily accomplished, and what yet remains to be done.

1. **Effluents.**—The success of a work is most frequently judged entirely by the effluent produced, generally in accordance with some more or less recognized standard of purity.

The question of standards is too large a one to enter upon here, more especially as the Royal Commission on Sewage Disposal

has issued a report upon the subject. (See Eighth Report of Royal Commission on Sewage Disposal.)

Taking a broad view it is probable that the criterion of purity suggested above, namely, an effluent which will not deteriorate the stream into which it flows is a comprehensive and practical one.

It allows for some advantage to be taken of dilution, if the volume of the stream be large in proportion to the volume of the effluent; it insures an automatic speeding up of authorities downstream, as these in the higher reaches, who have the initial advantage of clean water, do their duty; it is, in fact, in accordance with the judgment in the recent famous Birmingham *v.* Tamworth case.

The principle of judging an effluent by its effect on the stream into which it flows has many advantages. It is exceedingly difficult to obtain a true average sample of the effluent from any sewage works. Conditions vary from day to day and, indeed, from hour to hour. Land areas may have been recently plouged, and the effluent for an hour or two may be distinctly unsatisfactory. A sudden storm may push strong tank effluent through filters at a rate too great for efficient purification, or over the storm overflows without any treatment. Unless systematic sampling at short intervals is undertaken, either as part of the work of the staff, or by means of mechanical devices, many of these incidents will escape notice. Snap samples often give, on the other hand, either too good or too bad an impression of the character of the effluent.

But the character of the stream below the outfall is a permanent, and on the whole, a fair witness. Where gross obvious pollution is not in evidence, a body of knowledge is being obtained of the various forms of life which indicate good or insufficient purification. It is astonishing how a small amount of unbroken-down organic matter in an otherwise well-mineralized effluent will encourage the growth of masses of fungus.

The idea of the fish pond as an extra line of defence before the final discharge of an effluent into a stream, which has been successfully applied at many places in Bavaria, under the direction of Prof. Hofer is well worthy of careful study.

A consideration of the effect of an effluent on the forms of life and growth in a stream leads to the important question of disinfection, a subject which has recently been so ably dealt with by Prof. Phelps.

There is one point which, in the writer's opinion, has not been sufficiently studied in this connection, namely, the possible effect of sterilizing agents on the microflora and fauna of the stream other than bacteria. A comparatively small dose of chloride of lime will inhibit fungus growth, just as a small dose of copper will prevent the development of algæ. It is worthy of further study whether the addition of chloride of lime to an effluent, in sufficient amount reasonably to protect a water supply, may not at the same time upset the balance of life on which the continued healthy condition of a stream depends. Speaking generally it may, however, be said that, of the four problems referred to, the problem of the effluent has been carried furthest to a scientific solution.

2. The sludge problem is really the centre of the general sewage problem. The method of handling the solid matter, which in some form or other has to be separated from sewage conditions, the size and character of the filters, and the main question in the design of sewage works lies broadly in the allocation of expenditure as between sludge disposal and filteration costs. Thus very perfect clarification of sewage by heavy doses of chemical renders possible great economy in filter construction and maintenance, while with adequate filter area, it is possible practically to dispense with preliminary treatment altogether. How far expenditure is best incurred in one direction or another depends entirely on circumstances, and it is here that judgment and experience are called for.

The Fifth Report of the Royal Commission on Sewage Disposal was by no means unfavourable to chemical treatment in a number of cases. It may be doubted whether the dilute sewages resulting from the lavish use of water in American cities lend themselves generally to economical precipitation by chemicals.

The writer has had occasion lately to go somewhat deeply into the question of precipitation of sewage, and has concluded that chemical treatment is to be recommended where the following conditions predominate :—

(*a*) Where sludge disposal is cheap ; (*b*) where land for filters is restricted ; (*c*) where filter construction is expensive ; (*d*) where fall is limited for either coarse percolating filters or double contact beds ; and (*e*) where special trade refuse has to be dealt with.

Conditions (*a*) and (*b*) probably both apply in Glasgow, and to a less extent in Salford. Condition (*c*) depends largely on facilities of transport, which vary within wide limits. Condition (*d*) obtains, *e.g.*, at Hanley and elsewhere in the "potteries," and shallow percolating filters of fine material are employed. It is thought by some that with small material clogging takes place unless precipitation is, as a matter of fact, achieved at Hanley by means of the "slip" or fine clay from the pottery works, which comes down with the sewage. Ordinary septic-tank treament is likely to be disastrous for such filters, causing rapid blocking. Condition (*e*) is exemplified at Wakefield, where, owing to the presence of wool-scouring liquors and other troublesome trade effluents, chemical treatment by lime and ferric sulphate has been adopted under the advice of the writer.

Of course, the main difficulty with chemical treatment is the disposal of the resulting sludge. Apart from its quantity, the act that it contains a large proportion of precipitated soaps render

it unsuitable for use as a fertilizer, as it is not readily incorporated by the soil.

Should Dr. Grossmann's grease-extraction process, now being tried on a large scale at Oldham, or the partial carbonization process, now being taken up by Norwich and Huddersfield, prove successful, even to the extent of disposing of the sludge in a satisfactory manner without additional cost, chemical precipitation may have a more extended use than was at one time thought likely.

The use of the septic tank as a solution of the sludge problem has not proved altogether the success that was at one time hoped, but here as always in considering the sewage problem it is important that conclusions should not be too hastily drawn.

The defects which have shown themselves in the ordinary septic-tank process are nuisance both from the tank effluent and the sludge, and an excessive quantity of suspended solids in the tank effluent.

The Emscher tank (concerning which much has been written of late) seeks to remedy these defects by quickly separating the sludge and the effluent. The liquid portion of the sewage passes rapidly through the tank in a fresh state, while the suspended solids drop through a slot into a lower compartment, where the sludge is thoroughly digested under anaerobic conditions, the construction of the tank preventing any fouling of the effluent through escaping gases and suspended matters.

The tank certainly appears to be successful in eliminating nuisance both from sludge and effluent, and under certain conditions, has manifest advantages. The Manchester Rivers Committee has recently decided to instal a trial Emscher tank at the Withington sewage works, where the sewage is dilute and purely domestic, and the present tank space inadequate, especially in rainy weather.

Nevertheless, it is well that certain difficulties inherent in the Emscher tank process should be pointed out.

In the first place, the comparatively short time of settlement means that variations in the character of the sewage must be quickly reflected in the character of the tank effluent, and that the filters must be called upon rapidly to accommodate themselves to fluctuating conditions. This is not conducive to the development of the most efficient bacterial activity. These fluctuations will, of course, be accentuated when trade wastes are present in the sewage. One of the main advantages of the considerable time allowed for the sewage of Manchester to pass through the tanks at Davyhulme is that fluctuations of this sort get smoothed out to a large extent, at any rate, and that the filters have a more equable task to perform. In some cases large tank space may be a bulwark against possible disaster, as when on a recent occasion an acid chamber gave way at a works in the city, letting out many tons of vitriol into the sewage. The strong acidity of the sewage entering the tanks was, however, nearly neutralized by the mixing with the slightly fermented sewage present in the tanks, and the filters incurred no noticeable damage.

It appears to be recognized by the Emscher authorities that storm water, above moderate dilutions, will have to receive a separate treatment, and that ordinary stand-by tanks will still be necessary for this purpose, the sludge from which will have to be dealt with.

In any event, the suspended matters which produce the sludge in the Emscher tanks are those which settle readily, say in the space of two hours. The colloids, such as are eliminated by chemical treatment, have still to be reckoned with, and the character and extent of the filter beds designed accordingly. In many cases, this may mean that fine material cannot be used for constructing the filters, and the alternative adopted of deep filters of coarse material, with the possible resultant nuisance from flies, to be referred to later.

A third consideration with reference to the Emscher tank has been forced upon the writer's attention through a small experiment

in connection with the sewage of a public institution, where it has been possible to test, side by side, a small Emscher tank and an ordinary septic tank.

Here the sewage was very strong and, what is even more important, very fresh. In consequence, although an effluent free from visible solids and also from putrid odours was obtained from the Emscher tank, on analysis it was found to be less broken down than the effluent from the septic tank and less readily oxidized by the subsequent filtration process.

In the controversy between the advocates of anaerobic or aerobic methods of treatment, the essential biological and chemical reactions which must take place before nitrogenous organic matter is finally mineralized, particularly the dilution of the sewage and its alteration during its passage through long lengths of sewer, are often lost sight of by reason of incidental circumstances. When strong fresh sewage has to be dealt with, empirical conclusions drawn from ordinary town sewage cease to hold good.

This is especially so with the strong sewages often met with in tropical regions, where high temperature may coincide with restricted water supply.

The writer's researches in latrine sewage in Calcutta, in 1906, showed that preliminary anaerobic treatment in properly designed tanks gave better results than purely aerobic methods, and this conclusion has recently been confirmed by careful detailed experiments by Major Clemesha, Sanitary Commissioner for Bengal.

These researches showed that the bulk of the suspended matter was best broken down in a separate inlet compartment to the tank, but that distinctly better results were obtained, the longer time the whole body of sewage took to pass through the tank, up to a maximum of three days.

All these considerations would tend to show that, if the best results are to be obtained, the Emscher tank may need to be supplemented by some form of equalizing tank.

Some of the difficulties above indicated attach themselves to the Dibdin slate bed. The true function of this process does not seem to be very generally understood. The slate bed is not a filter in the sense of a percolating filter or contact bed, but rather an aerobic tank. The coarser suspended matters in the sewage deposit themselves, during about two hours' period of contact, on the surfaces offered by the slates and are afterwards digested by multifarious forms of life flourishing under aerobic conditions. The effluent from the slate bed should be treated as a tank effluent and filter space provided, in the usual way, according to its strength. In order that the filters may work to the best advantage, it is probable that the provision of "humus" tanks between the slate beds and the filters is desirable. Such tanks will have the double advantage of retaining solids washed away from the slate beds, and of equalizing to some extent the composition of the effluent passing into the filters. They have, the writer has heard, been adopted in a recent scheme for Harpenden.

The slate-bed process has undoubtedly been successful in many cases in dealing, without nuisance, with the sludge disposal portion of the sewage problem. When compared with continuous flow tanks, where the loss of fall involved is trifling, the process is somewhat handicapped by cost and by the fall needed for the slate bed as a preliminary process.

The foregoing section will have indicated that the character of filter to be recommended, whether contact bed, coarse percolating filter, or fine percolating filter, must depend to a great extent on the preliminary treatment used.

There are certain sewages where almost any kind of tank treatment is bound to result in nuisance. Especially is this the case where brewery refuse is present in the sewage in any large proportion. Considerable trouble from this cause has been experienced at Stratford-on-Avon, and treatment with lime and bleaching powder has had to be resorted to in warm weather in order to minimize the smell. At Burton, after heavy treatment with lime, the sewage is pumped directly on to land.

In such cases either the slate-bed method or direct treatment on filters of the Ducat type would seem to be called for.

Successful trials of the use of a layer of peat over the material of an ordinary percolating filter have been made under Dr. Dunbar at the sewage experimental station at Hamburg.

The writer has experimented with this method in connection with the disposal of the sewage of Market Drayton, which is particularly strong and offensive. At the adjoining parish of Little Drayton, a Ducat filter has been in successful operation for many years, and has been reported upon by the Royal Commission.

The type of filter apparently most in favour in America, and also to a less degree in England and in Germany, is the deep percolating filter of coarse material. It admits of the passage of large quantities of sewage without blocking, and eventually discharges as so-called "humus," a considerable proportion of the colloidal matter applied to it. Consequently it is, for practical purposes, everlasting. Filters of this type have been at work successfully at Accrington since 1898, or for 14 years. Unfortunately, the spraying of anything but fresh tank effluent on these filters is attended with considerable nuisance from smell, and whether the tank effluent be fresh or septic, the development of insect life, particularly flies and spiders, is often extraordinary. Instances could be cited of spray jets completely blocked with twisted spider webs; of ropes of web, like scarfs, from filter to filter; of small flies nearly covering the doorway of a cottage half a mile from the works, and so forth.

However good the effluent from such filters, and however economical their construction and maintenance, it cannot be said that such a process meets all sanitary and esthetic requirements.

Experience shows that if the surface layer of the filter is of fine material, the fly trouble is minimized, and this was one of the reasons for adopting a fine surface layer in the new filters at present under construction at Wakefield. Of course, such a fine layer presupposes good preliminary clarification, or a somewhat

restricted flow; and, again, the balance of advantage has to be considered.

There can be no doubt that the main advantage of the contact bed lies in its freedom from nuisance.

There have been no complaints nor causes for complaint in connection with the 100 acres now in operation at Davyhulme, or with the 40 acres or so now installed at Sheffield. The cost of maintenance of these beds has not been excessive, even with a thorough washing and partial renewal of the medium every five years.

Incidentally it may be mentioned that the "slurry" washed out from the filtering medium, after pressing with lime, drying, and grinding, finds a ready and profitable sale for direct use as a fertilizer of moderate strength, or as a basis for the manufacture of high-strength fertilizer.

The economical and the scientific solutions of the sewage problem are really coincident, and the more the two ends are borne in mind the more quickly will, the desired goal, be reached.

It is still possible to see costly devices installed at sewage works, when a little careful scientific investigation and thought would have shown that they could never achieve results proportionate to the outlay. Apart from actual analysis and measurement, it is easy to draw the conclusions that a special form of mechanical filter is removing large quantities of suspended matter when really either very little has been retained in proportion to the volume of liquid passing or the volume of liquid passing is much less than is assumed.

The cost of certain mechanical distributors, including repairs and loss of time, in proportion to the quantities actually filtered over lengthened periods, was ably dealt with some years ago by Mr. Watson.

The question of the desirability or otherwise of providing costly sewerage and sewage disposal works in country districts, where it is of the first importane to spend money to the best

advantage, especially in the provision of cheap houses, may well receive the careful joint consideration of the medical officer and the Sanitary engineer.

In many towns in India, for example, it is at present financially impracticable to undertake fully developed Western sewerage schemes. Provisional methods, with due reference to possible complete schemes in the future, have in consequence to be devised. Development on such lines may be wisest for many country villages or undeveloped towns.

The harmless return of excreta to the soil is subject, of course, to scientific principles, just as the more elaborate methods of the modern sewage works, and it is well that interest in the latter should not entirely divert attention from the study of more primitive but still frequently necessary methods.

There is need for careful investigation of the rate of change of suspended and coloidal matter in sewage under different conditions.

Closely connected with this question is the large field of research into the conditions of life of the various organisms in sewage works, and their relation to the sewage purification process and to each other.

Thus it will be seen that, while in a limited sense it may be stated that the sewage problem is solved, in that the general principles according to which offensive organic matter can be mineralized are now fairly well known, their detailed application will for many years to come afford work for the engineer and biological chemist.

It is gratifying to note that, particularly in America, the value of scientific research on this large problem has always been fully recognized, and that it is now the custom for any scheme of magnitude to be prefaced by preliminary scientific studies. The intelligent co-operation of the engineer and the biological chemist in this work is certain to justify itself by advancing each case nearer to the goal of perfection.

Since the above paper was written, Dr. Fowler was called upon to visit New York to consult with the Metropolitan Sewerage Commission of that city with regard to the disposal of the sewage of greater New York.

As a result, his attention was called afresh to the possibilities of purifying sewage by æration methods, especially in view of the interesting results obtained by the chemists of the Massachusetts State Board of Health, working on somewhat novel lines.

On his return to England, fresh researches were set on foot in several directions both at the Sewage Works of the Manchester Corporation and at the University of Manchester, resulting in what is now known as the "Activated Sludge" process.

This process, it will be seen later, fulfils the four criteria laid down at the beginning of the foregoing review.

THE ACTIVATED SLUDGE SYSTEM OF SEWAGE PURIFICATION.

It has long been known that if sewage is exposed to the air for a sufficient period of time, the organic contents are gradually oxidised with the formation of a deposit of so-called "humus" and the final production of nitrates from the ammonium salts and the nitrogenous organic matter.

The present methods of sewage purification contemplate for the most part some form of tank treatment for the removal of suspended matters followed by a process of filtration.

All these processes produce a deposit known as sludge, greater or less in amount, according to the process used, chemical treatment of the crude sewage producing the greatest amount. The sludge from chemical treatment is very bulky and colloidal in nature.

Most sewage disposal works produce several kinds of sludge, tank sludge, either from septic settling or chemical precipitation tanks, and filter sludge, that is the deposit in the humus tank following percolating filters or the slurry from the periodical wash-

ings of the material of the contact beds. The greater the clarification in precipitation tanks, the greater the tank sludge production.

None of the forms of sludge generally produced are of much value as manure, owing to the low percentage of nitrogen and the difficulty of handling greasy and colloidal matter.

Dr. Fowler very rightly says that to solve the sludge problem is to solve the main sewage problem.

For some time past, experiments have been carried on in the Laboratories of the University of Manchester at the Manchester Corporation Sewage Works, by Dr. Fowler and his colleagues with the object of clarifying sewage and effluents with the minimum production of sludge. The Manchester experiments have been directed to the elimination of the necessity for extended artificial surfaces of any kind and to the completion of the process in a simple open tank.

Early in the investigations, a colleague of Dr. Fowler's, Capt. Mumford, discovered a specific organism, a bacterium in colliery waters, which is known as M. 7, which has the property of precipitating hydrated oxide of iron from solutions containing salt of iron together with organic matter.

Crude sewage, from which the grosser solids had been removed by sedimentation, was treated with a small quantity of iron salt and inoculated with the organism above referred to and aerated for several hours. Perfect clarification took place and a deposit containing a very high percentage of nitrogen, as much as 10 per cent. was formed.

The effluent from this process could be nitrified at very high rates on percolating filters. But, inasmuch as the preliminary settlement of the sewage was called for by this process, with the production of ordinary sludge, and as the effluent still required final treatment on filters for complete oxidation, the method although having many advantages, did not realise the object of the researches.

In the meantime, experimental results accumulated in the Laboratories at the Manchester Corporation Sewage Works, and these experiments showed that if the aeration process was pushed sufficiently far, it was possible, under suitable conditions, to completely purify raw sewage with the production, on the one hand, of a perfectly clarified, fully nitrified, effluent saturated with dissolved oxygen, and, on the other, of a deposit which settles rapidly and completely, and is inodorous and readily drained, and which contains, in a dry state between 4 per cent. and 5 per cent. of nitrogen.

The first process in this system is to manufacture activated sludge and this is done by aerating a portion of the sewage until chemical tests show that the soluble ammonia is completely converted into nitrates. This may take a longer or shorter time, according to the season of the year, as the temperature has a considerable bearing on the matter. But, usually speaking, it will last for some weeks.

The granular deposit is allowed to completely settle and the liquid carefully decanted off. The tank is then refilled with sewage and aeration recommenced until oxidation of the ammonia is once more complete. This time a shorter period will suffice and the same process is repeated, allowing the successive deposits to accumulate until they have attained about 20 per cent. by volume of the tank; oxidation of the sewage should then be complete in a few hours.

Once having obtained a certain amount of activated sludge, it is possible to inoculate other tanks from the deposit which now rapidly accumulates.

After many months of investigation and experiment in the Laboratories of the Manchester Corporation Sewage Works, results justified experiments being made on a larger scale and at Manchester and Salford tanks have now been at work for some time dealing with quantities of sewage up to 100,000 gallons per day.

The experiments made at Salford by Mr. S. E. Melling, F.I.C., are worthy of more than a passing note. While experiments were

still in a small way at Manchester, Mr. Melling boldly introduced the system at Salford.

The method of sewage treatment at Salford is chemical precipitation of screened sewage (lime and iron salts) and sedimentation followed by filtration; interposed between the precipitation tanks and the percolating filters is a system of roughing filters. Half of one of the sections of a roughing filter, with a capacity of 12,000 gallons, was exposed and the floor was prepared so as to obviate any appreciable settling out of the sludge during either the blowing or the quiescent periods. When the first charge of crude sewage was introduced the air was forced through at a pressure of about 2 lbs. The procedure at first decided upon was to continue aeration until such time as a diminution in permanganate reducing power along with sensible nitrification were observed, followed by settling for a sufficient period and careful decantation.

At a later date matters were accelerated by the addition of copperas at the rate of 16 grains per gallon and also of washings from slurry free from coarse detrital matter which had been removed from the filtered effluent carrier.

The results at first fluctuated from day to day, but it would appear that the maximum effect, if any virtue could be attached to it, was brought about in approximately 48 hours.

The next procedure was to accelerate the accumulation of sludge and to oxidise it as thoroughly as possible, and further slurry washings from the effluent carrier were added to the already existing sludge and the aeration was continued with little cessation for a considerable time.

After two months, fillings with crude sewage were recommended and it was immediately found that in 24 hours there was a 50 per cent. reduction in free and saline ammonia and 80 per cent. purification based upon the 4 hours' oxygen absorption test. An active nitrification was in evidence.

Experiments were continued for another two months with varying successes, but at last, when working with a 30 per cent.

volume of sludge, it was found that in two hours there was a purification of 91 per cent. based on the oxygen absorption figure and that the free and saline ammonia had been reduced from 2·64 parts to 0·028 parts per 100,000 with nitrous and nitric nitrogen 1·17 per 100,000.

At the annual General Meeting of the Association of Managers of Sewage Disposal Works, held on December 9th, 1915, Mr. W. H. Duckworth, F.C.S., Manager of the Salford Sewage Works, gave some very interesting results of experiments with Activated Sludge at the above works during the 12 months previous to the above date.

Mr. Duckworth's object was to ascertain whether a reduction of the three hours aeration of the sludge could be made, whether the system could be worked satisfactorily during the winter, whether the mode of aeration with open jets was satisfactory, and whether a continuous flow of sewage in tanks could be aerated satisfactorily. On all these points Mr. Duckworth has attained important and satisfactory results.

As to the shortening of the time of aeration he has proved that it is possible to reduce the three hours to one hour, and to still obtain a satisfactory effluent; the percentage of purification obtained for one hour was—

Alb. N. H.	75 per cent.
4 hours' oxygen	88 ,, ,,

Mr. Duckworth states that the experience gained during the past 12 months has led him to the conclusion that the time of aeration can be cut down to one-third of what was found possible a year ago, and further than that the remarkable clarification approaching drinking water clarity which was often obtained during holidays and Sundays, when many works are shut down and are not giving their trade waste, and it is indicated that with a domestic sewage only, the results obtained work out to a still higher percentage of purification than that given above, and he expresses the opinion that with domestic sewage the time factor might be further reduced.

As regards the temperature, many of the experiments were made with a crude sewage temperature as low as 51° F.

Speaking of the open jets for supplying the air to the crude sewage, Mr. Duckworth states that these jets were cleaned at the beginning of December 1914, and that they have worked practically continuously since then, and are still giving good results.

Important experiments were made to apply the continuous flow system with satisfactory results. The experiments took place in four settling tanks having a total capacity of 6,000 gallons.

In the first trial about 34,000 gallons per day were passed through the tanks. This gave a percentage of purification of—

Alb. N. H.	78 per cent.
4 hours' oxygen	87 ,, ,,

In the next trial 50,000 gallons per day were passed through and the percentage of purification obtained was—

Alb. N. H.	78 per cent.
4 hours' oxygen	89 ,, ,,

A final experiment was made with 60,000 gallons and gave a percentage of purification of—

Alb. N. H.	74 per cent.
4 hours' oxygen	90 ,, ,,

The best results have been obtained with 20 to 25 per cent. of Activated Sludge. Mr. Duckworth sums up his article by stating that the results have been obtained with a crude sewage, not very effectually screened and with little detritus settlement, and containing large quantities of trade waste, and that the conditions may be described as being somewhat adverse.

The above experiments are eminently important and it is hoped they will be continued, and at a later date the actual cost of the process may be given, from practical experiments on a large scale.

An estimation has been made of the cost of the process by colleagues of Dr. Fowler, Messrs. E. Ardern, M.Sc., and W. T. Lockett, M.Sc., and given in a paper read before the Society of Chemical Industry on September 30th, 1915, and the cost of aeration

per million gallons of sewage is given as 11*s.* for the minimum and 27*s.* 6*d.* for the maximum air supply.

The system would appear to have passed now beyond the experimental stage and some of the advantages claimed for the process are that the sludge problem is solved and the tank sludge is inoffensive, easily dried and handled and is large in nitrogen and is a valuable fertiliser, the effluent is brilliant and fully oxidised, there is a great reduction in the area of land required at sewage disposal works, capital costs are reduced, because the purification is completed in tanks alone without the necessity for filters and the tank capacity is less than that required for septic or sedimentation treatment. The whole plant is free from complications, easy to construct and maintain, chemicals are dispensed with and a revenue is obtained from the sale of fertiliser recovered from the sludge.

Since the above described researches were published, experiments have been carried out at a number of centres in the United States invariably with success.

The Sewage Commission of the City of Milwaukee, U. S., have made extended trials of the Activated Sludge System.

In January 1916 a large installation on the continuous System was started having a designed capacity of 2 million gallons per 24 hours.

The Sedimentation Tanks, however, were found to be unable to pass more than half the above quantity, because the slope of the tanks was too great and the sludge was carried away with the effluent. therefore the velocity was reduced until only 1 million gallons per 24 hours was dealt with. The "filtros" plates which were used gave trouble by becoming clogged on their top surfaces and this necessitated a higher pressure of air than was anticipated.

The following points however have been determined :—

(1) That more air is required with sewage at a temperature of 50° Fahr. than with sewage at a temper-

ature of 60° Fahr. to produce equal results in each case.

(2) That circular tanks are not so efficient as rectangular, and that they require more area to treat a given volume of sewage than do rectangular tanks.

(3) That mixed sewage and activated sludge must not be run through conduits as the tendency is for the sludge to settle out immediately in the conduits and become Septic. The sedimentation tanks must be connected to the aerating tanks without intervening conduits.

(4) That the settled sludge must be constantly and completely removed from the sedimentation tanks to prevent septic action.

The experiments made at Milwaukee in the direction o drying the sludge are interesting. Dried sludge, with 10 per cent. of moisture in it, contains 4½ to 5 per cent. of Nitrogen calculated as Ammonia and from 0·6 to 0·7 per cent. of available phospheric acid. In addition there is ¼ to ½ per cent. of potash and from 3 to 4 per cent. of fatty matter.

This dried sludge is being sold at from 38 to 62 per ton, and the cost of obtaining the product is from 33 to 50 per ton depending on local conditions.

The dried sludge as it stands is a good fertiliser and commands a large market.

A considerable quantity of the activated sludge from the Milwaukee tanks has been treated by a process brought out in the Packinghouse District of Chicago, by which the sludge containing 55 per cent. moisture is freed from fats by naphtha, dried by indirect heat to 7 per cent. moisture, after which it is bagged ready for shipment as a fertiliser, the fats being distilled and put into barrels.

The cost of the process is said to amount to between 21*s.* and 25*s.* per dry ton, and the value of the resultant material to about £2-10-0 based upon its nitrogen and fat.

Comparative pot experiments, carried out by Dr. Bartow of the University of Illinois and which have been confirmed in England, show activated sludge to be superior to all other forms of nitrogeneous manure. At Salford, trials have been made of tanks working on the continuous principle at the rate of 60,000 gallons per day, with excellent results.

Existing tanks at Worcester and Stamford are being converted into tanks for the activated sludge process, to be operated continuously. At Worcester, the proposed tanks should be capable of dealing with 1,000,000 gallons per day.

Further researches at the Withington Works of the Manchester Corporation, dealing with domestic sewage, have shown that if oxidation of the putrefactive matter of the sewage is alone desired; together with thorough clarification, much shorter periods of aeration will suffice than if complete nitrification of the ammonia is attempted. It will depend, therefore, upon circumstances what degree of purification is needed and the cost of the process will vary accordingly.

THE S. O. S. PROCESS OF TREATING SEWAGE SLUDGE FOR THE RECOVERY OF VALUABLE PRODUCTS.

THE recovery of by-products from sewage sludge is not a new problem, but the treatment of sewage sludge so that none of its component parts are wasted (is of recent date, and marks a large advance in the final treatment of sewage. The S. O. S. (Sewage Oil Syndicate) Process is primarily a commerical project, but at the same time it largely solves the problem of dealing with the immense quantities of sludge now so difficult to dispose of.

The " Process " aims at the destroying and rendering harmless the organic matter in sludge and the obtaining by such distillation, by-products, the value of which shall cover the cost of the operation and leave a commercial profit.

It requires the suspended solids in the sewage to be precipitated by some chemical treatment, and the sludge

rendered solid either by filter pressing, lagooning, or by a Centrifuge.

The sludge should not contain more than 75 per cent. of moisture, any less quantity making the subsequent process easier.

The first part of the "Process" is to place the sludge in an ordinary mortar mill, where it is chemically treated at a small cost. From this mortar mill it passes on to a travelling wire belt contained in a chamber kept at a temperature not exceeding 350° F. the heat being derived from either the spare gases from retorting, waste flue gases, or whatever method may be considered in any particular case most economical. In travelling over this belt the moisture in the sludge is reduced to about 15 per cent. This drying operation is conducted at a comparatively low temperature so as to prevent the loss of the volatile products in the sludge. From the dryer the material is passed into a large hopper from which it is fed into retorts and kept at a certain temperature for about four hours until complete carbonisation has taken place and during that process the products are led off by an eduction pipe into containers as is done in ordinary gas manufacture. The products obtained will vary with different sewage and in many cases trade waste will enormously increase the yield, but in dealing with ordinary domestic sewage the following may be taken as an average distillate.

Yield of crude oil = 17 gallons per ton of material.

,, ammoniacal liquor = 30 gallons.

From the crude oils there is a yield of water free oil of 13·6 gallons per ton, of which the analysis is as follows :—

Specific gravity of	.. 15° C.	= 0·934.
Light oil boiling under	..170° C.	= 5·0% in volume.
,, ,, ,, between ..	..170° C.	
and	..230° C.	= 19·0% in volume.
,, ,, ,, between ..	..230° C.	
and ..	..270° C.	= 17·9% in volume.
,, ,, ,, between ..	..270° C.	
and ..	..330° C.	= 31·4% in volume.

Leaving a residue of 26·7%

The crude oils give excellent results in oil furnaces and for semi Diesel type engines, the calorific efficiency being approximately 18,400 B.T.U. with a flash point of 58° F.

The first fraction gives an excellent motor spirit, the others being eminently suitable for burning oils, and lubricants, the residue gives organic pitch valued at £6 per ton.

At the temperature most suitable for retorting, there is with domestic sewage a yield of 5,000 to 6,000 cubic feet of gas per ton of material, which, after being passed through a scrubber, is led back to assist in the heating of the retorts, thus materially reducing the expense of fuel. With a plant dealing with say 100 tons of sludge per day, the gases would be more than sufficient to do the retorting without any other fuel. From the scrubbing of this gas there is recovered per ton of material 3 gallons of light spirit boiling under 160° C. with a specific gravity of 0·774 and ·8 gallons of a spirit boiling between 160° C. and 200° C. with a specific gravity of 0·806. The light spirit is water white and suitable for motor spirit, while the solvent spirit has a value for many purposes.

The ammoniacal liquor can be readily converted into sulphate of ammonia, and with the scrubber the liquor gives a yield of approximately 65 lbs. per ton of material.

The residue left in the retort is a black friable substance, the composition of which varies in accordance with the quality of the sludge, the precipating agent, and the temperature of retorting, but an average sample will give from 15 to 20% of carbon, 20% of calcium carbonate, a little phosphoric acid, and the balance siliceous matter. This residue can be used for various purposes. If the carbon is separated it can be used for the manufacture of paints, printer's ink, etc., while the residue as a whole, forms an excellent base for the manufacture of artificial fertilisers, having a fair manurial value in itself, and a point of special importance to engineers is that it may also be used for the sedimentation of solids in crude sewage.

The working cost and profits largely depend on the size of the plant, but with a plant dealing with from 30 to 50 tons of sludge per diem the working cost should be well under 10*s*. per ton, whilst the costs in larger plants are proportionately decreased, as no more labour is required to run a large plant than a small one.

The earlier experiments of this "Process" were naturally conducted in a Laboratory, but early in 1913 a small plant on the Barking Urban Council Sewage Farm was erected, capable of dealing with 3 tons of sludge per day. This plant consisted of two sets of retorts, three of cast iron and three of fireclay, so placed that the charge was partially distilled in the iron retorts, and by means of a sliding door transferred to the clay retorts where the operation was completed. A condenser was fitted together with separating tanks, a coke tower to scrub the gas, and a small ammonia plant. The charge is fed into each retort by hand, steam at about 70 lbs. pressure being admitted to prevent the degradation of the oils. The vapours were drawn off by means of a small exhauster, the uncondensable gas being passed through the coke tower and thence into the furnace and burnt. The object in having two sets of retorts was to effect the operation in two stages keeping the temperature of the iron retorts as low as possible.

On the results obtained by 12 months working at Barking in conjunction with laboratory experiments the present Sewage Oil Syndicate was privately subscribed and a plant was by agreement with the Town Council of Wimbledon erected on their Sewage Farm to deal with the entire sludge from the Disposal Works.

Here great difficulty was at first experienced in dealing on a large scale with the hygroscopic moisture contained in the sludge, but as a result of experiment and research this has now been satisfactorily solved.

By the improved treatment it has now also been proved that instead of the ordinary horizontal gas retort, vertical retorts can be used, and a complete installation is now being put in, in place of the horizontal type, by which not only are products better

both in quantity and quality, but working costs are very materially reduced whilst the first cost is also much less.

THE CENTRIFUGE SYSTEM OF TREATING SLUDGE.

EXPERIMENTS with centrifugal force applied to the treatment of crude sewage have of late years been carried out with a machine known as a "Centrifuge."

The principle is by no means new, and a "cream separator" is a notable example of its success. For some years an installation has been working at Tadcaster, a town of 10,000 inhabitants, in the West Riding of Yorkshire. Here the whole sewage amounting to 250,000 gallons per diem is being passed through a B. T. W. Centrifuge and a B.T.W. Sludge Dryer. The former separates the sludge from the sewage and the latter dries it and turns it into powder which is sold as manure, at prices as high as £2-10-0 a ton.

At Dublin also in connection with the Hydro-Sewage System a Centrifuge is used for the treatment of the sewage, after the greater part of the solids in suspension have been removed from it by the application of yeast.

For some years also Messrs. W. Owen Travis, M.D., Bar.-at-Law, and Robert Sturgeon, A.M.I.C.E., have been making investgations and experiments with a Centrifuge. The outcome of these experiments is the production of a machine which successfully separates suspended solids from the sewage and discharges them automatically from the Centrifuge in the form of a stiff cake, having a percentage of moisture of from 55 to 65.

Two experimental machines were made by Messrs. Hughes & Lancaster, Limited, one 16½ ins. and one 30 ins. diameter. Both the machines have been successfully tested under all sorts of conditions. The former of the two machines, through the courtesy of the Borough Engineer of Wimbledon, was erected and worked by electric power at the Disposal Works under the actual conditions which would be met within any suburban sewage disposal works.

Fig. No. 39 is a drawing of the Centrifuge made by Messrs. Hughes & Lancaster. This machine has been recently improved on by Mr. Robert Sturgeon. The following is a brief description of the machine.

When a liquid is admitted to a cylindrical vessel, which is rotating rapidly, it climbs up the sides until the surface of the liquid takes up a line approximately parallel to the axis of rotation. The centrifugal force produces in the liquid a pressure which

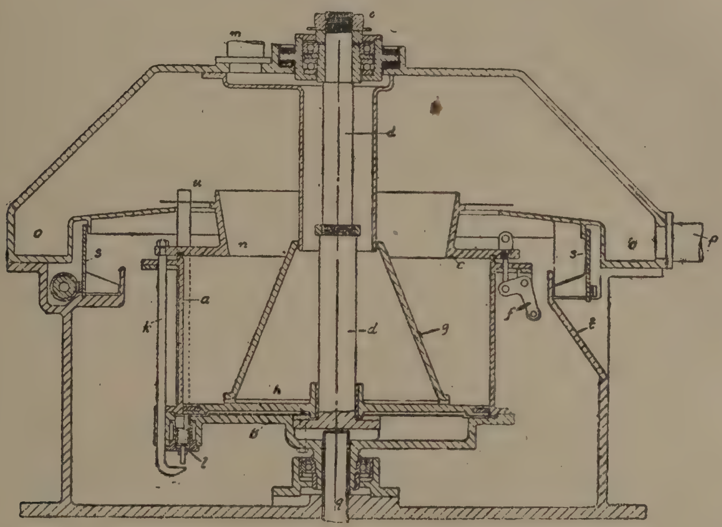


FIG. No. 39.

acts in all directions—both axial or radial—so that if one of the end covers was able to slide freely in the cylinder, the axial pressure due to the liquid would give it an axial movement.

The application of centrifugal water pressure is now used for the first time to operate the mechanism of a self-discharging centrifuge. In this case the apparatus consists primarily of a cylinder and piston. The piston operated by means of the pressure produced in a liquid under centrifugal force.

Referring to Fig. No. 39 which consists of two half sections, one through the valves in the bottom cover, and the other through the levers which hold down the top cover.

The cylinder *a* has a fixed cover *b* at the bottom and a movable cover *c* at the top. The movable cover is held on its seat by weights under centrifugal force, acting through the bell crank levers *f* which allow of a limited lift. The piston *h* slides up and down the shaft. Attached to the top cover *c* are vertical valve rods *k*. When the piston reaches its top position it lifts the cover off its seat, thereby causing the valve rods to open the valves *l*.

The shaft is rotated by means of the pulley *e* and the cylinder and all parts connected thereto revolve with it.

METHOD OF WORKING.

The machine is started, and the liquid enters it through the pipes *m*, and the conical chamber *g*. It is propelled to the periphery, where it deposits its solids, and is discharged over the concentric weir *n* into the trough *o* whence it is carried away through the pipes *p*.

When it is required to discharge the deposited solids, the supply of liquid is cut off and water is admitted to the underside of the piston through the pipe *q*.

The axial pressure produced in the water by centrifugal force eventually overcomes the forces acting downwards and lifts the piston—compressing the solids in so doing.

As the piston rises the surface liquid is steadily displaced by the thickening wall of solids until it is all drained off.

Eventually the pressure on the top cover overcomes the pull of the levers and lifts the top cover, discharging the solids on to the revolving plate *s*. From there they are scraped by the stationary blade and fall down the chute *t* into a suitable conveyor.

The supply of water under the piston is then cut off.

As the cover *c* lifts, the lever *k* opens the valve *l*, allowing the water to escape through the pipe *u* into the trough *o*.

Eventually the top cover closes, due to the pull of the levers overcoming the falling pressure under the piston.

Sewage is again admitted and the pressure produced in it by centrifugal force, presses down the piston, closing the valve (1) in so doing.

The cycle is then complete.

It is a matter of interest to note that the water pressure required to operate the machine is entirely self-produced, and is not dependent on externally developed pressure. The maximum axial pressure produced in the water used for lifting a 48″ piston at 600 R.P.M. is about 28½ tons.

The Wimbledon experiments showed that a considerable degree of clarification of the sewage could be obtained by centrifugal action.

The following figures illustrate what was actually done with crude sewage passed through a centrifuge, given in parts per 100,000 :—

Crude sewage	.. 12·8	Effluent	.. 2·0
Do.	.. 38·4	Do.	.. 3·6
Do.	..7100·0	Do.	.. 60·0

The sludge cake discharged from the machine varies in consistency to some extent and depends largely on the nature of the sewage, and partly on the adjustment of the machine. The addition of a small percentage of lime to the sewage is necessary to facilitate the settlement of the suspended solids usually amounting to 35 grains per gallon.

Since these results were obtained Mr. Sturgeon has been enabled to further develop the apparatus, and has succeeded in greatly reducing the power required to drive the machine, improving the effluent and increasing the capacity of a machine of a given size.

A 48″ diameter machine with these improvements will treat 70,000 gallons of sewage per hour at approximately 15 H.P. of which 12 H.P. is taken up in friction.

The uses to which a centrifuge can be put are numerous, and among the chief is the separation of solids from any liquid containing suspended matters.

The rapidity of the system is very great, avoiding as it does the storing of offensive liquids for several hours; which makes it possible to have disposal works actually in a town with a large saving of space.

THE B. T. W. DRYER FOR THE CONVERSION OF SEWAGE SLUDGE INTO MANURE.

In reducing the suspended solids in crude sewage sludge cake, the Centrifuge is undoubtedly successful. But for the adaptation of that sludge, another and very important process is necessary, *viz.*, the drying of it without injury to its manurial properties and the turning of it into powder suitable for manure.

In the Summer of 1913 the Author visited Tadcaster by the courtesy of the B. T. W. Patentees, saw their Dryer at work, and was much impressed with its efficiency.

The drying of sewage sludge is by no means an easy problem because during the process it has a tendency to form lumps in which the particles adhere so closely that air does not easily penetrate their interior, and effective means are necessary to break it up during the whole time it is being dried.

Another difficulty is the offensive smell from the organic matter in the sludge, which gives rise to an intolerable nuisance from the foul gases if they are discharged into the air, and yet a third difficulty exists, that of the danger of burning the sludge if heated to a high temperature when practically all its manurial value is lost.

The B. T. W. Dryer appears to deal with all these difficulties in a most effective way.

In regard to the first difficulty—the sludge is fed into two revolving and inclined cylinders set one above the other. There

are projections inside the upper cylinder on which the sludge is caught and carried around nearly to the top, when it falls to the bottom, and by the slope and rotation movement of the cylinder is slowly carried forward. The sludge is therefore continually falling through the current of hot air flowing in the cylinders, and is turned over and over on the heated plates of the cylinders. In order to counteract the tendency of the sludge to form into large balls it is constantly broken up by rows of projecting teeth fixed to the inner periphery of the upper cylinder. These teeth carry the sludge around to a row of knives attached to a fixed girder which runs from end to end of the cylinder; and are so placed that they pass between the rows of teeth, and break up any large lumps of sludge resting on them. At intervals also are placed two or more small rollers; these rollers are carried on arms hinged to the girder and rest on the cylinder near the bottom. The rotation of the cylinder causes the rollers to revolve, and the small lumps of sludge are carried under the rollers and flattened against the sides of the cylinder. Immediately above each roller is a scraper, which removes the sludge and throws it to the bottom. By these devices the sludge is maintained in a divided state, so that by the time it arrives at the end of the upper cylinder it is so far dried that the pieces will no longer adhere together.

In the lower cylinder, projecting vanes carry the sludge around to the top of the cylinder, and drop it to the bottom, during this stage of the process the thin pieces of sludge become so dry that the repeated falling breaks them up into small particles. The latter part of the lower cylinder, towards the outlet, has no lifting vanes and the material slides down as the cylinder revolves and therefore is kept longer in contact with the hot plates and the hot current of air. There is an air-box at the outlet, in which is fixed a pair of finishing rolls through which the dried sludge passes and finally falls out as powder. The sludge is then in a condition for application to the land.

To deal with the second difficulty, that of providing against the nuisance from the foul gases. The furnance is designed with a large grate and with forced draught for burning low grade fuel. The fan which maintains the circulation of the hot air through the dryer, also delivers the foul air under the grate of the furnace and into the combustion chamber; the gases are therefore subected to so high a temperature that they are completely burnt and rendered innocuous.

B. T. W. DRYER.

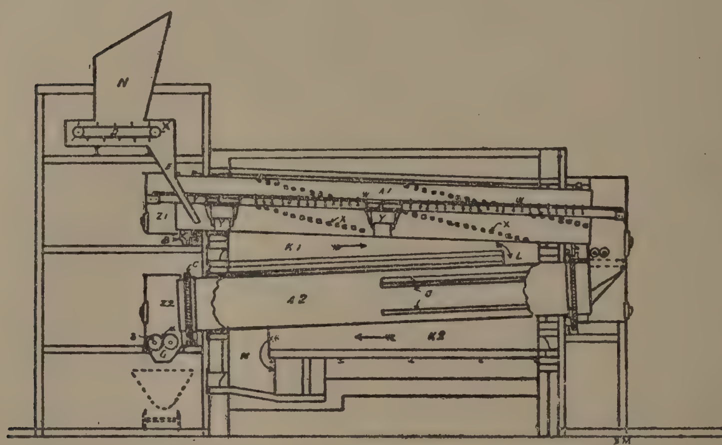


FIG. 40.

The third difficulty is that of the danger of burning the sludge during the drying process. In order to make use of the highest temperature without burning the sludge, the furnace gases and the sludge must travel through the apparatus in the same direction so that the wet sludge on entering the upper cylinder receives heat by conduction through the plates of the cylinder from the hottest gases, and the dried sludge as it leaves the cylinder is only subjected to the low temperature of the cooled gases; in addition, a circulation of air by means of the fan at a low temperature is maintained through the interior of the cylinder in direct contact

with the sludge. This has the effect of keeping the sludge at a temperature too low for ignition.

The value of the manure obtained from the sludge will vary largely according to the nitrogen content of the sludge, and it is not easy to state a definite price for it. But at Tadcaster it is sold at £2 to £2-10-0 per ton.

The cost of converting the sludge into manure with this dryer is estimated at about 8 shillings per ton.

Fig. No. 40 shews the details of the B. T. W. Dryer.

THE DICKSON PROCESS OF TREATING SLUDGE.

THERE have been a large number of patents taken out for the recovery of fertilisers from sewage, spread over many years, but the Dickson process for this purpose seems to have obtained a larger measure of success than most. It has been working at Dublin for the last four years. The installation was constructed by the Hydro-Sewage Contractors, Ltd., Westminster, who hold the patents for the process.

The sludge from the sewage is obtained from sedimentation tanks. The system consists of two processes—

(*a*) The fermentation of the crude sludge by the addition of 0·5% of its dry weight of ordinary yeast. (*b*) The drying of the resultant sludge mixed with compounds containing phosphates and potash, to produce a fertiliser.

The sludge is pumped into a tank, and in this tank the yeast mixed with water is added to it. This admixture of sludge and yeast is then pumped through what is known as a "heater," consisting of a number of pipes placed in the path of the hot air from the furnace; these pipes deliver into a fermenting trough or troughs, under each of which is placed a hot air duct, and the mixed sludge and yeast is kept at a temperature of 90° F. for 24 hours. The result of this fermentation is a distinct separation of the water from the sludge, and the sludge rises to the surface of the water with a density of 83% of moisture instead of 95%, after which the

water is readily drained away from beneath the surface sludge. This is the first process. Before the fermented sludge is passed on to the dryer it is mixed with a compound of phosphates and potash in about equal proportions of the dry weight of sludge, the mixture then contains about 73% of water, and in that condition it is pumped into the dryer.

The dryer consists of a cylindrical vertical casing, containing a series of arms and platforms, the latter being perforated, revolving upon a centre shaft fixed between the arms and the platforms.

The sludge mixture is pumped in at the top of the casing, and is scraped over the surfaces of the plates, and gradually falls to the bottom. Air at a temperature of 450° F. is blown in at the lowest point and passes out at the top, this air after being used to heat the sludge in the fermenting troughs is passed through the furnace, and being exposed to a high temperature is perfectly deodarised before escaping to the atmosphere.

The dried product at the bottom of the casing passes on to a disintegrator, consisting of a revolving paddle which beats up the product into a powder, which is blown out at one end of the machine by a draught of hot air.

The process is then complete, and the product is a manurial powder rich in fertilisers. In Dublin this powder has been sold at an average figure of £3-15-0 per ton.

The introduction of the yeast into the sludge is said to produce a stimulating food for the putrefactive bacteria, and one of the most interesting, and extraordinary features of the system is the rapidity with which the sludge is separated from the liquid.

At Dublin, however, the process goes further, and the liquid from the fermenting troughs, after the solid matter is taken from it, is passed through a specially constructed centrifugal machine, in which it is fully saturated with oxygen and the effluent leaves this machine with practically no odour and is said to be innocuous to fish life.

The centrifugal machine contains a cage filled with filtering material such as sand, peat, or other material.

Means are provided in the machine for the automatic removal of the inner surface of this filtering material and for its replacement by fresh material when necessary. The process of filtration and aeration is continuous. The film of solid matter deposited being constantly renewed the aeration which goes on keeps the remainder of the filtering material clean and sweet, no matter how foul the incoming liquid may be.

It is stated that the cost of treating the sludge amounts to about £1-5-0 per ton of dried sludge, and the cost of a plant for that purpose is about 10 s. per head of population, while a combined plant for treating sewage and sludge would cost £1-10-0 per head of population.

The Author is much indebted to Dr. Gilbert Fowler, C.Sc., F.I.C.; for the first pages of this Chapter, in which he gives a most valuable review of the progress of sewage purification up-to-date.

The four methods of treating sewage sludge are all new and of great interest to Sanitary Engineers, and the Author feels that before closing the Chapter it is desirable to give his own views on each.

The processes are all different and three out of the four will certainly have places in future in Sewage Disposal Works.

Activated Sludge.—There is no doubt that Sanitary Engineers are much indebted to Dr. Gilbert Fowler, and to our American friends in Milwaukee and elsewhere, for their investigations into this process. That it is sound there can be no doubt, and that it will in the near future be used extensively all over the world, there is also little doubt.

The activation of sludge, once the first cost is done with, is economical, and the resultant has a very distinct value as a fertiliser, while the sewage effluent will require little or no more treatment to enable it to be discharged into rivers and streams.

The area of land at Sewage Disposal Works where Activated Sludge is manufactured can be much restricted.

The process should be especially valuable in Eastern Countries where manure is so much required, and has mostly to be imported at great expense.

The S. O. S. Process of treating sludge, while entirely destroying that sludge, retains all its useful products.

It must however be remembered that a previous treatment such as pressing, lagooning or centrifuging, is probably necessary to the financial success of the process, and it is assumed in the previous article that the sludge is handed over in one of the three conditions abovementioned.

The pressing of the sludge with 50% moisture probably costs 2s. 6d. per ton and the addition of chemicals for sedimentation purposes means usually £1 per million gallons of sewage, but there is no doubt at any rate in the British Isles, a very great supply of sludge available at different disposal works in a condition to suit this process and which the authorities are only too glad to dispose of either free or for a small consideration.

There is not the same economy in land as with Activated Sludge, but on the other hand the obtaining of the products, which have a ready sale, is a certainty, and the process should have a future before it.

The Centrifuge.—The combination of a Centrifuge with a B. T. W. Dryer is a practical proposition. Here as in Activated Sludge the final result is a fertiliser.

The value of the sludge is probably not so great as in Activated Sludge, but that it is considerable is shewn by the fact of its ready sale at Tadcaster.

In this process, the further treatment of the effluent is reduced, because of the great and quick elimination of the suspended solids.

The Dickson Process depends for its success on the supply of yeast. This supply at Dublin is assured because of the near proximity of the Guiness Brewery, but the same does not apply to all places, and more especially is this the case in Eastern towns. It does not seem to the Author to be a process which is likely to

find universal favour, although certain of the accessory plant is well devised and may probably find useful application.

None of the above processes have as yet stood a great test of time, and Engineers will await with interest, the future knowledge which must shortly be available and the Author has no doubt that the first three processes will meet with a large measure of success.

CHAPTER VIII

Tank Gas

In dealing with the subject of gas obtained from a Liquefying Tank, the Author has decided to relinquish the use of the term "septic gas" hitherto employed, and to substitute therefor the term "tank gas," as being a more practical term in relation to the particular gas in question, which consists of four constituents, namely, marsh-gas (CH_4), hydrogen (H), nitrogen (N), and carbon dioxide (CO_2); for while this combination has no specific name in Chemistry, the use of the word "septic" to represent it may be considered to be a misnomer, particularly because that word has a specific use in Surgery and refers to the putrefactive or animal poisons which permeate the blood, and, having exclusively organic origin, is associated with Bacteriology. Under these circumstances, the change is rendered desirable, and has the sanction of practicality at least to recommend it until a better term is found to supersede it.

In the opinion of the Author, there is a future for tank gas in the East; for, in the first instance, beyond the first cost of covering a liquefying tank and the construction of a gas holder and a purifier, there is no further cost for generating the gas. Then again, after being purified, the tank gas can be used for power in a gas engine to actuate any machinery, and also for heating or lighting. *Quisque sua lampas!*

At Matunga, all the gas that can be obtained from the liquefying tank is made use of in one or other of the three above-mentioned ways. The daily supply is fairly constant, while the quantity is only limited by the population, the average temperature, and the pressure at which the gas is drawn off. It must be remembered

that the gas is highly explosive, and as this is the case, care is necessary in dealing with it, the insertion of a piece of gauze in the gas delivery pipe being desirable to prevent firing back.

EXPERIMENTS AT MATUNGA.

From the early part of 1902 to 1906, the Author experimented with the gas generated in the liquefying tank at Matunga. Early in 1902 the No. 1 Compartment of the tank was covered with a galvanized iron gas-tight cover of a semi-circular shape, which was laid on the side walls on a jointing of red lead and bolted firmly to the masonry. This mode of fixing the cover did not prove altogether successful and many coatings of pitch were subsequently required to make it gas-tight.

At a later date, when covering the second compartment of the tank, the iron cover was so constructed as to rest on a ledge in the walls some nine inches below the surface of the sewage, which thus formed a water seal. This method proved to be quite satisfactory and allowed of the cover being placed in position without any trouble. At one end of each cover two inspection doors are fixed to give access to the tank when necessary.

In covering the liquefying tank, it must be remembered that no other material is so suitable as iron, as admixture with the outside atmosphere is fatal to the well-doing of the gas. With any material such as brick-work or concrete, even when covered with a layer of earth, the gas will find its way through. Even with an iron cover great care must be exercised in making the joints, which should invariably be made with tape.

In the earlier experiments that were made, which are described in the Author's *Oriental Drainage*, only a small gas-holder, 5 feet in diameter and 4 feet high, was used. At that time only one compartment of the liquefying tank was covered. When the second compartment was covered, two large gas-holders were erected: the larger of these is capable of holding 1,200 c.ft. of gas, and the other 600 c.ft., while the smallest holder holds 60 c.ft. only.

All three holders are in communication with each other and can be filled one from the other at will. The gas is drawn off from the roof of the tank through a 4-inch cast iron pipe by means of the suction action produced by the gradual raising of the gas-holder by counterbalance weights, and is first led into the purifier, a small drawing of which is given in a corner of Plate No. 55. In the purifier, the gas is passed through slaked lime to remove the carbonic acid gas. After passing through the purifier, it is conducted by a 4-inch pipe into the gas-holder. The section of the gas-holder shews two pipes fixed in the centre, one a 4-inch pipe for filling the holder and the other a 2½-inch pipe for the delivery of the gas, for whatever purpose it may be used. The diameters of the entry and exit gas pipes are governed by the size of the installation.

Much care is required in the construction of the gas-holder. After the gas-holders are once in position, leaky joints are very difficult to deal with. A gas-holder should be rivetted on the spot at which it is intended to be erected, and all the joints should be most carefully made with tape. The same remark applies to the purifier. At the lowest points of the gas pipes a cock should be inserted for the removal of any condensed water. This is very necessary, for water accumulates in the pipes to such an extent as in time to completely stop the gas from passing through. Another necessary precaution is the placing of a piece of copper gauze on the entry and exit pipes to prevent any chance of the gas firing back.

Plate No. 55 which is a plan of the Biological Installation at Matunga, shows also the details of the gas arrangements now in use.

A similar experiment with gas was made at the Exeter Sewage Disposal Works at Belle Isle by Mr. Donald Cameron, M.I.C.E., the late City Engineer, and there the gas was drawn from the cover of the tank, by an aspirator or fan, to supply the power for working a gas engine and for illuminating purposes. It is said

that at Exeter, roughly, one cubic foot of gas was obtained per head of population per day at an average temperature of about 55° F.

Dr. S. Rideal, who analysed the gas at Exeter on two occasions, gives it composition in percentages by volume as follows :—

Carbonic Acid	0·3	0·6
Marsh Gas	20·3	24·4
Hydrogen	18·2	36·4
Nitrogen	61·2	38·6
Total ..	100·00	100·00

Broadly speaking, it may be said that tank gas is made up on an average of 20 to 24 per cent. of marsh gas and 18 to 36 per cent. of hydrogen, or, say, altogether an average of 50 per cent. of combustible gases ; so that the quantity of gas necessary for each brake horse-power for working a gas engine would be double that of ordinary coal gas.

An analysis made by Major Collis Barry, I.M.S., Chemical Analyser to Government, of the gases collected from the tank at Matunga is as follows :—

Carbonic Acid	5·32
Marsh	21·25
Hydrogen	13·52
Nitrogen	60·00

It will be noticed that the composition of the Matunga gas closely corresponds to the analyses made by Dr. Rideal of the gas from the Exeter Works. An important difference is, however, apparent in the percentage of the Carbonic Acid Gas, which is much larger at Matunga than at Exeter. This is no doubt due to the difference in the temperature of the sewage and probably the pressure at which the gas is drawn off. Carbonic acid gas is very soluble in sewage, the amount which the sewage can contain being dependent upon the temperature of the sewage and upon the pressure of the gas over the surface of the sewage.

The above results are borne out by several analyses of the gas made by Captain Glen Liston, I.M.S., the percentages of one of which are as follows:—

CO^2	16·0
CH^4	23·9
H	11·99
N	48·00

Captain Glen Liston makes the following interesting remarks on the gas after several analyses:—

"CO^2 variable from 5%, when engine was going fairly well, "to 11% when just going and to 16% when not going at all. No "oxygen, or an almost inappreciable quantity, was ever found "in the gas. No CO (Carbon Monoxide) was ever found. The "amount of Hydrogen varied from 12 to 20 per cent. The amount "of CH^4 varied from 24 to 32 per cent. The amount of N varied "from 48 to 60 per cent."

It was found that when the percentage of CO present in the gas was high, the engine would not go, and that the engine went best when the CO^2 was low, hence the necessity for getting rid of the CO^2. The method at first adopted was defective, because the lime was not slaked properly. The presence of carbon dioxide is very harmful, both in the working of the engine, lighting, or the burning of the gas. It must be got rid of. The constituents of the gas which are useful for combustion or lighting are hydrogen and marsh gas. The amount of these two gases present was variable. The best results are obtained when the highest percentage of hydrogen is present. Hydrogen, when it is burnt, produces only water vapour, while marsh gas produces carbon dioxide and water vapour. The former constituent has a damping effect of further combustion.

The larger part of the gas consists of nitrogen. This is a diluting constituent. It was present in variable quantities, no doubt depending on the various factors mentioned above. The gas is often so diluted with nitrogen that it will not explode when mixed

with ordinary air under atmospheric pressure. When this is the case, an increase in the pressure at which the gases are exploded will cause combustion. This is important when a gas engine has to be worked. The gas must be well compressed before explosion. In analysing the gas, oxygen has often to be added to effect an explosion. The quantity of nitrogen present in the gas probably depends on the pressure at which the gas is drawn off. The lower the pressure in the tank chamber below atmospheric pressure, the greater will be the quantity of nitrogen in the tank gas.

The tank gas at Matunga is utilized in three ways—(*a*) to actuate a gas-engine, (*b*) to light the compound and buildings, and (*c*) for cooking.

In 1902, an Otto Gas engine, of ½ H.P. nominal, capable of developing 3 Indicated H.P. with a consumption of 22 c.ft. of coal gas per H.P. per hour, was erected. This engine works a 3-inch centrifugal pump of the ordinary type, fixed in a brick chamber six feet in depth. The pump lifts the effluents from the liquefying tank to a tank fixed some ten feet above the ground. From this tank the effluent flows by gravitation to the contact beds and filters described in the previous Chapter.

Further experiments are necessary to determine the best type of engine to work with tank gas, and it is probable that an engine built to work with Mond, a "Producer Gas," would be the most suitable. At Matunga the gas engine for many months in the beginning gave uncertain results, and had to be considerably altered before it could be got to work satisfactorily. A regulating valve had to be placed on the air admission pipe to reduce the quantity of air in the mixture, and at the same time more gas had to be admitted than would be the case with coal gas. The engine still suffers from contracted gas passages, and the result is that it will not give off the rated horse-power on the brake. A shorter ignition tube had to be put in to secure an earlier ignition, as it was found that frequent misfires occurred with the standard tubes originally attached to the engine.

The engine still occasionally misses one stroke in four, otherwise it gives great satisfaction and works without difficulty. It is possible that some of these difficulties would be overcome and a considerable saving in gas effected by using magnetic ignition, with an arrangement for advancing or retarding the spark.

The upkeep of the engine is exceedingly light, lubrication being the principal item of cost. Approximately this size of engine will use about 130 c.ft. of gas per hour of work. The experience at Matunga has been that to get the best results from the engine, the CO_2 must be almost entirely eliminated.

Practically, the whole of the lighting of the Acworth Leper Asylum at Matunga is now done with the tank gas derived from the liquefying tanks. Pipes varying in size from $2\frac{1}{2}$ to $\frac{1}{2}$ inch at the lamp posts have been laid from the gas-holders all over the Asylum grounds.

The burner for tank gas is a modification of the one usually used for ordinary coal gas with an incandescent mantle. The alteration chiefly affected the size of the opening which admits air to mix with the coal gas. As tank gas requires considerably less oxygen for its complete combustion than coal gas, the air opening in the burner had to be much smaller. A collar to regulate the size of the opening gives the most satisfactory results.

When the pressure is greater, more gas will be used and the mantle will become hotter, giving out more light; in other words, it will give a higher candle-power. When the pressure is low, less gas will be burnt, less heat evolved, the mantle will be less brilliant, and the candle-power will be less. Any kind of incandescent mantle which is satisfactory with coal gas can be used with this gas. The amount which each gas lamp will burn varies according to the candle-power desired.

The kitchens at Matunga are now fitted with gas rings and much of the cooking is done with tank gas. There are eight stoves so fitted and the food for the patients is cooked daily at these. The consumption of gas is heavy, but as its production costs nothing,

that is of little moment. About 300 c.ft. of gas are used both morning and evening, and the saving in wood fuel to the Asylum is large.

At another installation which is under construction in connection with the sewerage of Bombay, it is proposed to utilize the gas for burning the screenings in a small district.

Having dealt with the experiments at Matunga with tank gas, it will be well to consider the conditions which influence the quantity and quality of the gas.

At Matunga, the population is 430 persons. For the last twelve months, careful observations have been taken of the amount of gas obtained, the temperature of the air, and the temperature of the sewage. The amount of sewage passing through the liquefying tank is at present equal to 30 gallons per head per day. The conditions affecting the quantity and quality of the gas may be summarized under the following four heads :—

I.—Quality of sewage.
II.—Pressure at which gas is drawn off.
III.—Bearing which temperature has on evolution of gas.
IV.—Velocity of sewage and disturbance of sediment.

I.—**Quality of Sewage.**—The amount of gas produced will depend greatly on the quantity of nitrogenous and non-nitrogenous elements present in the sewage and undergoing disintegration.

Major Ernest Roberts, I.M.S., in his paper published in "Scientific Memoirs by Medical Officers of the Army of India," Part XII, 1901, states that with the natives of India the unabsorbed proteid from vegetable foods amounts in the excrement from 10 to 20% of the total ingested, and that from 30 to 50% of the cellulose leaves the body in its integrity.

Professor Sims Woodhead, M.D., stated in his evidence before the Royal Commission on Sewage Disposal that, in the ordinary domestic sewage, the nitrogenous constituent of the sewage is always relatively small, the greater bulk being non-nitrogenous cellulose or the like, and that the cellulose is converted into carbonic

acid and marsh gas. It would appear from this, with other things being equal, that the gas obtained from the sewage in the East should be equal in amount to that obtained from the sewage in the West.

Professor Sims Woodhead is probably correct when he says that the non-nitrogenous elements in the sewage, especially vegetable matter, are best for the formation of tank gas. As the large mass of the natives of India are vegetarians, the sewage of the East is likely to be a better producer of gas than that of the West.

Any addition of what is known as "trade refuse" will usually rather retard the formation of gas than otherwise. At the present time, practically nothing is known as to what bacteria are necessary for the production of gas, affecting at the same time a satisfactory purification of sewage. But it is an established fact that it is possible to cultivate suitable bacteria in a liquefying tank by depositing in it some of the sediment taken from a tank which is in full working order. This has been done often in Bombay, and many new tanks have been successfully supplied with the required bacteria cultivated from the sediment of the Matunga Liquefying Tank.

The dilution of the sewage has a very important bearing on the quantity and quality of the gas formed. As an instance of this, the Author can cite an interesting experience obtained at the Empress Mill in Bombay. Here a large installation of latrines used by some 6,000 mill hands has been connected to a covered liquefying tank, to which is attached a gas installation similar to that at Matunga. The gas obtained is used for a gas engine and for lighting the Mill compound.

From the first, the liquefying tank was cultivated with bacteria from Matunga, and in a short time gas commenced to be evolved. The amount of water used at these latrines was in the beginning equal to only one gallon per head per day. This quantity in the course of three months proved to be inadequate for complete purification in the tank, and although large quantities of good

gas were given off, the tank became almost choked, while the effluent was only partially purified and had a very offensive smell.

The amount of water was increased to three gallons per head and the immediate result was a better effluent and also an increase in the evolution of gas, which was of excellent quality for purposes of combustion. A further increase of water to five gallons per head resulted in a further improvement. At five gallons per head, the quality of the gas was still excellent and after purification gave very good results in the engine and for lighting.

The above is interesting as shewing that even with exceedingly strong sewage and very little dilution, good gas can be obtained though not in such quantities as is possible with sewage diluted under ordinary circumstances.

II.—**Pressure at which Gas is drawn off.**—The pressure at which tank gas is drawn off has an important influence not only on the quantity of the gas but also on its quality, as well as on the purification of the sewage.

The Author has found that if, in a covered liquefying tank, there are no arrangements to allow the gas to pass or to be drawn off as it is formed, the carbonic acid gas is absorbed by the sewage and purification is not so rapid or complete.

An ordinary glass gauge half filled with water has been fixed on the cover of No. 1 Compartment of the liquefying tank at Matunga for the determination of the pressure of the gas in the cover and of the vacuum necessary for drawing it off into the gas-holder. Observations have shewn that although the gas has been allowed to remain in the cover without being drawn off for a day or two, no pressure has ever been indicated in the gauge. On the other hand, as before mentioned, this has been extremely detrimental to the purification of the sewage. It has also been noticed that if gas is allowed to remain in the cover, it gives off some of its carbonic acid gas, which is absorbed by the sewage. When the largest gas-holder is drawing gas at Matunga, the gauge shews the vacuum to be equal to about half an inch of water.

Further careful experiments are necessary to determine the pressure at which the greatest amount of gas can be obtained consistent with good quality.

It is always necessary to employ some power to remove the gas from the cover of the tank. This may be done either by suction as before mentioned of by means of a fan or vacuum pump. It has been found that if gas is drawn off too rapidly or in too great a quantity, the quality of the gas for purposes of combustion is very inferior, and great difficulty is experienced in using it successfully.

III.—**Bearing which Temperature has on Evolution of Gas.**—Charts have been prepared from time to time shewing (*a*) the temperature of air, (*b*) the temperature of the sewage, and (*c*) the quantity of gas removed from the tank at Matunga. It must be remembered while considering the amounts of gas recorded below, that only two compartments of the tank out of four have been covered, and it is probable that these amounts would be increased by at least 20% if the whole of the tank were covered and the full quantity of gas that could be given off by the sewage collected :—

The charts shew that temperature has a large bearing on the amount of gas produced. The lowest mean temperature of the sewage registered in 1906 was on the 12th January 1906. It was then 71·5° Fahrenheit. The lowest mean temperature of the air on that day was 67·8° Fahrenheit, and the amount of gas obtained from the two compartments for 24 hours on that day was 1,050 c. ft. On the 30th of the same month the mean temperature of the sewage was 73° and that of the air 78·8°. The amount of gas obtained on that day was 1,350 c.ft. On the 15th February 1906, the mean temperature of the sewage was 75° and that of the air 80°, and the amount of gas obtained was 1,550 c.ft. The above shews that, with a rising temperature, the volume of gas is proportionately increased. It may be mentioned that in all cases the pressure at which the gas was drawn off was uniform. In May—the hottest month of the year in Bombay—the mean temperature

of the sewage is about 89°. As all the three gas-holders were not in work in May 1905, it is not possible to say exactly what amount of gas would be evolved at the temperature of 89°, but it would probably be far in excess of that obtained with the above temperatures. In the opinion of the Author, it would be quite safe to calculate upon an average volume of 3 to 4 c.ft. of gas per head of population per day throughout the whole of the twelve months.

IV.—**Velocity of Sewage and Disturbance of Sediment.**—The velocity at which the sewage passes through the liquefying tank has also an important bearing on the quantity and quality of the gas; for it stands to reason that when the sewage passes rapidly through the tank, purification is incomplete and the quantity of gas evolved is therefore less. In the opinion of the Author, the maximum velocity of the sewage in order to attain the best results as regards both the purification of sewage and the evolution of gas should not exceed one foot in three seconds.

An interesting experiment was tried in both the covered compartments at Matunga with an "agitator" for stirring the surface of the sediment. The agitator consisted of a flat bar of iron attached to chains, one end of which passed out through the end walls of the tank. It was found by dragging the agitator over the surface of the sediment that a much larger quantity of gas was evolved than under ordinary circumstances; but it was of such impure quality that it could not be used for working the engine and was also of very little use for lighting. It evidently contained not only a large excess of CO_2, but it was also deficient in marsh gas and hydrogen.

A few concluding remarks will not be out of place here as to the general use of tank gas. In the first place, there need be no anxiety or doubt as to the possibility of obtaining gas from a scientifically designed liquefying tank as at Matunga, where the use of tank gas has now been brought to such a state of perfection that from day to day the gas is removed from the liquefying tank, purified,

passed into a gas-holder, and used for the purposes enumerated earlier in this Chapter with as great a certainty as the drawing of water from a tap.

It would be out of place here to enter into any detailed discussion as to the methods employed in gas analysis, but a few remarks on a fairly accurate and practical method for analysing tank gas will probably serve a useful purpose. Very little is yet known of the conditions which influence the production of gas in sewage and still less is known of the qualities and composition of the gas evolved in the complicated putrefactive changes which take place in a liquefying tank; and therefore any progress in this direction can only be attained after a large number of analytical observations have been made under varying conditions.

A simple and practical method, capable of being carried out with a fair degree of accuracy by a Medical Practitioner or a Sanitary Engineer will help greatly in the solution of this difficult problem.

A proper use of the apparently waste gas from sewage, as will be seen in the earlier part of this Chapter, leads not only to the saving of a considerable sum of money in lighting and heating, but enables an Engineer to get over such practical difficulties in the disposal of sewage as those connected with finding a suitable fall. The possible use of the properly purified gas in the destruction of solid waste material, rubbish of all kinds, and sweepings must be kept in mind.

Since the Author left India for Egypt in 1906, little further has been done in continuing these gas experiments, but the foregoing account shews that it is practical to collect the gas and make good use of it.

CHAPTER IX

Surface Water and Sub-Soil Drainage

ASSUMING that a separate system of drainage has been decided on, the question of disposing of the surface and sub-soil water of each district then calls for consideration.

The amount of rain which falls in a district is, in most centres, officially observed and recorded, and there are few places now where that information cannot readily be obtained for a series of years sufficient to enable a just average to be determined.

In a Separate System of Drainage, the capacity of the sewers must provide for that amount of rain which falls on such roofs and on such open paved surfaces enclosed by houses as cannot drain to the surface-water drain in the street without a special connection. The reason for this is that it is very undesirable to have both a sewage and a surface-water drain within house premises, as there would then be the risk of unsanctioned sullage connections being made to the surface-water drains, which would generally be more convenient from the householder's point of view.

Wide fluctuations of rainfall occur at different places, even in one district, and, as a rule, the rainfall increases with the elevation. A Meteorological Observatory, such as exists in Bombay, is of the greatest assistance to the Engineer, as valuable data extending over many years can generally be obtained therefrom.

However heavy the annual rainfall may be, if it were evenly distributed over that period it would not be a serious matter to deal with; but this is not the case.

The rainfall comes in heavy storms at uncertain times and at different rates, especially during the wet season, and the question

to determine is what are the heaviest rates of rainfall in short periods that will have to be dealt with.

The maximum intensity of a storm usually lasts but a few minutes, seldom more than ten, and this fall on a large city is often very partial over a large area. These storm falls may be divided into three classes.—

(1) A rate of fall within certain limits which may be expected at any time during the rainy season.

(2) One within higher limits, five or more times in ten years

(3) A phenomenal deluge owing to "cloud bursts," etc., taking place at most irregular intervals many years apart. In the bulk of cases the drains could not be designed to take the last class.

To provide for the flood water from the 2nd class of storm may require a drain of 3 or 4 times the capacity of that which would take the first, and to take the 3rd, two or three times that of the second.

Providing for the first class only would probably result in flooding one or two times, almost every year, for the 2nd class flooding at intervals of several years, and for the 3rd perfect immunity.

The truest economy will be to construct drains to take the floods from the 2nd class and in most exceptional cases only those from the 3rd class.

In designing a scheme of surface-water drainage, the rainfall, the configuration of the land, and the area paved and built upon are the chief considerations.

In the case of towns on the sea-coast, the waters from high-lands should be separated from those of the low-lands: "high-lands" include lands at or above the level of the high-water mark of ordinary spring tides, and "low-lands" those below that level.

The waters from high-lands should be taken by drains discharging directly into the sea by the nearest route, the outlets being protected by means of tidal flaps. Those from low-lands will have

to be stored during the time of high water and discharged into the sea through sluices at the ebb tide.

In the case of high-level drains discharging continuously and directly into the sea or a river without provision for storage, the maximum hourly rainfall is the chief factor in determining the size of such drains. Tables should be prepared from meteorological data to ascertain how many times a year the hourly rainfall exceeds certain quantities, and from such tables the maximum hourly rainfall to be provided for can be easily ascertained.

As an example, the following table shewing the number of times the hourly rainfall exceeded the given amounts in ten years

Year.	Under $\frac{1}{4}''$ per hour.	$\frac{1}{4}''$ to $\frac{1}{2}''$ per hour.	Above $\frac{1}{2}''$ to $\frac{3}{4}''$ per hour.	Above $\frac{3}{4}''$ to $1''$ per hour.	Above $1''$ to $1\frac{1}{2}''$ per hour.	Above $1\frac{1}{2}''$ to $2''$ per hour.	Above $2\frac{1}{2}''$ to $2\frac{1}{2}$ per hour.	Above $2\frac{1}{2}''$ to $3''$ per hour.
1886	497	31	17	8	5	4	2	1
1887	654	46	14	4	2	7	1	0
1888	479	39	9	4	0	1	0	1
1889	562	37	12	4	1	0	0	0
1890	620	46	10	0	3	0	0	0
1891	469	49	8	7	6	2	0	0
1892	622	71	20	11	4	1	0	0
1893	476	45	7	4	1	0	0	0
1894	597	46	6	0	2	0	0	0
1895	534	56	7	4	9	0	0	0
Averages	551·0	46·7	11·0	4·6	3·3	1·5	0·3	0·2

(1886—1895) in Bombay will be found interesting. It will be seen that there were on an average only 5·3 hours in a year when the hourly rainfall exceeded 1 inch. Therefore, in Bombay, all high-level drains may be designed to carry 1 inch of rainfall per hour.

In the case of low-lands, the method for determining the size of the drain, etc., is different. It should be ascertained how many hours per tide, on an average, storage will be required, and the

amount of the maximum rainfall for that number of hours consecutively should be obtained from the meteorological data, and storage, drains, etc., calculated for and provided accordingly.

Consideration must also be given to the amount of the rainfall that will flow off the surface of the ground. In fully built-upon areas, such as will be found in the centres of towns, it will be necessary to allow for all the rainfall to flow off, for the percentage that will soak into the ground is not an appreciable amount and need not be considered.

In suburban districts with gardens, etc., 65 to 75 per cent. of the rainfall must be provided for in a surface-water scheme, but in rural and sparsely populated districts only 10 to 20 per cent. need be taken into consideration. No definite rule can be laid down for the amount that will flow off in rural districts, the nature of the soil naturally having much to do with that amount.

The following example of the data used for surface-water in the sewerage scheme of a large town in South America will be found useful as a guide.

Wholly separate system with an allowance for some storm-water from some back roofs and yards, which cannot be taken into rainfall sewers in streets, in the built over parts of the city.

Average rainfall, 100 inches a year.

Rainfall to be provided for 3 inches an hour. This rate occurs about 4 times in a year.

Adopted percentages of run off from different surfaces—

Slated roofs	90 per cent.
Tiled roofs	85 ,, ,,
Asphalt roadways	90 ,, ,,
Paved roadways	80 ,, ,,
Macadam roadways	50 ,, ,,
Gravel roadways	40 ,, ,,
Earth roadways..	20 ,, ,,
Earth backyards	20 ,, ,,
Paved backyards	70 ,, ,,
Lawns and Gardens	5 ,, ,,
Public Parks	5 ,, ,,

MEASUREMENTS OF IMPERVIOUS AREAS IN DIFFERENT DISTRICTS, WHICH MUST BE DRAINED TO SEWAGE SEWERS.

No.	Class of Residents.	Class of buildings.	Houses per hectare.	Population per hectare.	Impervious area per house. Sq. M.
1	Busy and thickly populated quarter working classes and works.	One and two story buildings and shops.	30	173	62
2	High class residential quarters.	Fine large houses ..	17	125	190
3	Mixed, all classes ..	Shops large and small houses.	9	52	....
4	Middle class ..	Ordinary houses ..	20	130	113
5	Business quarter ..	Banks, warehouses, shops, etc.	30	75	167
6	Natives and poor classes.	Shacks and poor class houses.	9	57	....
7	Best class residents	Fine houses ..	1	7·5	....
8	Middle class ..	Medium sized houses.	9	75	114

ADOPTED DATA.

Average future population of the City 150 persons per hectare. Dense centre of the City, Impervious area, 180 M. sq. per hectare—

Dry weather flow 7 c.ft. per head per day.	1·5 c. ft.	per hect. per minute.
Wet weather flow ..	7·9 c.ft.	„ „
Total ..	9·4 c.ft.	„ „

Average portions, Impervious area, 120 M. sq. per hectare of city—

Dry weather flow ..	1·5	c.ft. per hectr. per minute.
Wet weather flow ..	5·3	„ „ „
Total ..	6·8	„ „ „

Suburban districts, Impervious area, 75 M. sq. per hectare—

Dry weather flow	..	1·5	c.ft. per min. per hectare.
Wet weather flow	..	3·3	,, ,, ,,
Total	..	4·8	,, ,, ,,

One inch of rainfall in depth over one acre per hour is equal to 3,630 cubic feet, or 22,687 gallons per hour, or just one cubic foot per second. Consequently, drains designed for an hourly rainfall of one inch should be capable of discharging as many cubic feet per second as there are acres to drain.

In India, where the rainfall is usually confined to a specific season of the year, heavy daily falls are not uncommon, but they are usually not of long duration, and such flooding, as will temporarily occur, soon disappears and is more or less immaterial. In districts where the rainfall is small, the storm-water is generally loaded with impurities, particularly at the time of the first flood, analyses showing the liquid to be almost as impure as sewage; subsequent flows may, however, be comparatively pure.

The considerations which govern the directions of sewers in a sewerage scheme, will be even more applicable to the drains in a surface-water scheme, that is to say, they should always, if possible, follow the natural drainage of the district, and in this way nature provides the outfalls at which the surface-water will discharge. The number of outfalls is not restricted as in a sewerage scheme, and this tends considerably to economy.

The calculation for the size of surface-water drains is not difficult, the Engineer having decided on the amount of the maximum rainfall per hour and on the percentage of rainfall which will flow off the district to be drained. All the water from such of the roofs of the buildings as are not drained into the sewers is led by eave gutters and cast-iron pipes into a house gully or discharged on to the roadside water tables or into the roadside drains, the water thence flowing to the nearest water-gully connected with an underground drain. The system of surface-water drains will naturally

commence with open roadside drains or water tables, the former being constructed of sizes determined by the area and the rainfall to be disposed of.

Fig. 41 shews a roadside drain, 12 inches × 18 inches deep. The wall on the roadside is built of rubble masonry in lime mortar, 15 inches in thickness, while the inner wall is constructed of $4\frac{1}{2}$ inch brickwork, resting against a compound wall or plinth of a house. The foundation is formed of lime concrete, and the invert of a 4-inch or a 6-inch channel pipe. The haunches are filled up with cement concrete and the whole of the interior rendered with cement plastering. The roadside wall is built within six inches of the ground surface and is finished off with stone khankis or kerbing, 12 inches in width, 15 inches in tail, and 6 inches in thickness.

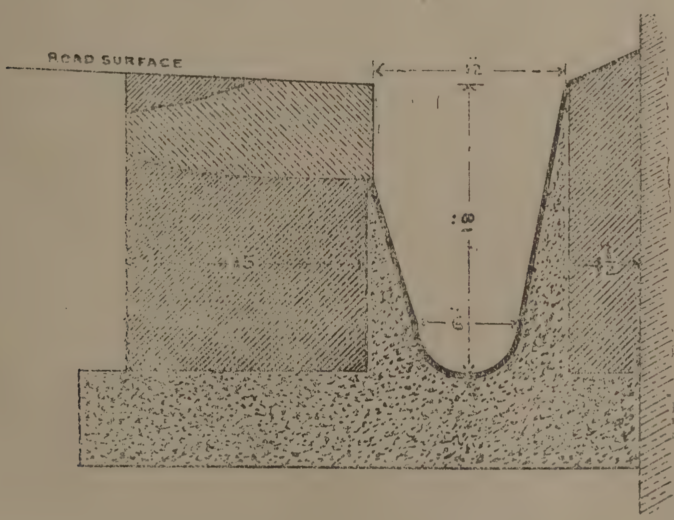


FIG. 41.

The next transition is to underground pipe drains of stoneware or cast-iron, from 6 inches to 18 inches in diameter, the next being to underground masonry drains, covered with stone slabs, 6 inches

in thickness, as shewn in Fig. 42 which gives a section of a drain 2 feet by 2 feet in area. The foundation is laid in lime or cement

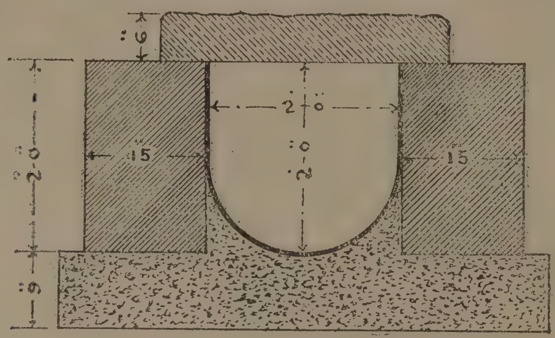


FIG. 42.

concrete, 9 inches in depth, the former being used in dry, and the latter in wet ground. The walls are built of rubble masonry in lime mortar, 15 inches in thickness, and the half-round invert formed of cement concrete, the whole of the inside being rendered with cement and sand (1 to 1) ½ inch thick.

The sizes of the drains will increase in accordance with the quantity of the water to be discharged and various sizes of such drains are shewn in Plate 58.

To ensure efficient drainage, all roads and streets should be constructed with a camber of not less than 1 in 40, as shewn in Fig. 43, and the sides finished with a line of slab stones, 15 inches by 12 inches by 4 inches thick, set in lime concrete, and generally

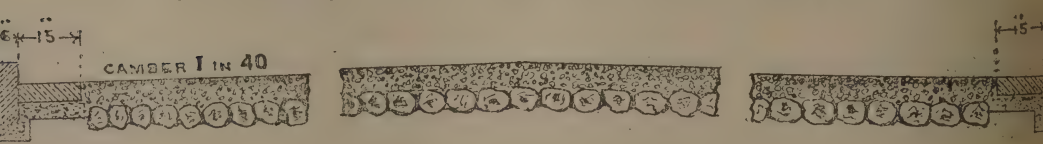
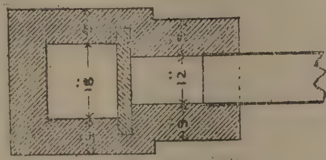


FIG. 43.

known as water tables, on which the surface-water will naturally flows. These water tables should grade each way at a slope of not less than 1 in 200 to a sealed chamber or water-gully connected with the underground surface-water drain in the road.

Figs. 44 and 45 shew a satisfactory type of surface-water gully. It will be noticed that the trap or seal of the water gully is 9 inches; the bed of the chamber is constructed of a 9-inch layer of lime concrete, the invert being formed of cement concrete; the walls are constructed of brick work in lime mortar, the whole of the inside being rendered with cement and sand (1 to 1) ½ inch thick; the parda or diaphragm is of blue cut-stone, smooth dressed and so fixed as to dip into the water to a depth of 9 inches and dividing the chamber into two parts; the part of the chamber nearer the underground drain is covered with 6-inch stone slabs, while the other part is brought up to the road surface, and covered with a cast-iron grating, 20 inches by 20 inches, resting on a cut-stone rebated curb, 9 inches by 6 inches. The depth of the seal of surface-water gullies in India should never be less than 9 inches on account of evaporation, which so rapidly takes place in this country.

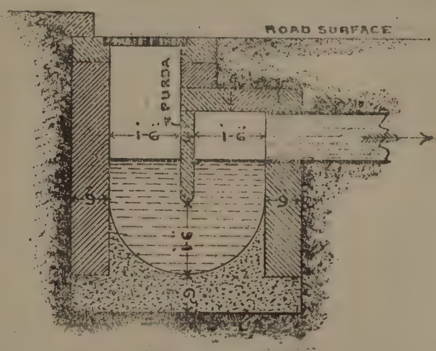
WATER-GULLY.



Plan.

FIG. 44.

WATER-GULLY.



Section.

FIG. 45.

Figs. 46 and 47 are two surface-water gullies, the "Wakefield", made by Messrs. Wragg and Sons, and the "Borough" by Messrs. Doulton.

The Author has found that either of these gullies are better than a gully constructed of brick-work or concrete. The

Wakefield pattern has been used largely in the sewerage of Port Said with considerable success.

The Wakefield gully comprises a rectangular body with an ordinary swan-neck outlet and its special feature is the manner in which the body of the gully is divided into compartments in order to provide a catch-pit and an independent trap.

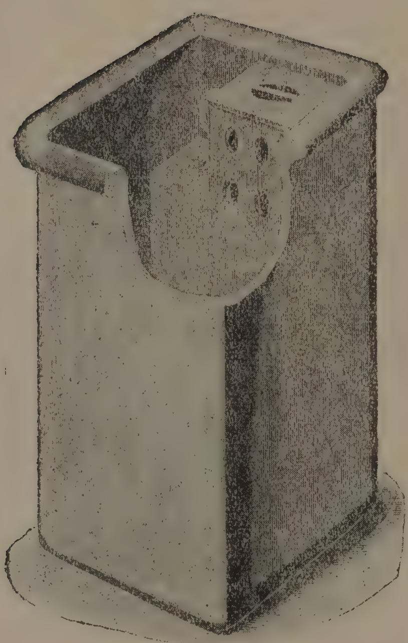


FIG. 46.

FIG. 47.

A diaphragm extending from the bottom upwards divides the body into two unequal parts of which the larger forms the catch-pit, and the smaller forms the trap. The seal of the trap consists of a cross partition in the smaller chamber, having its lower part cut away to allow the passage of water.

Surface water and detritus is received in the catch-pit chamber, and water overflows into the trap through holes situated near the top of the main diaphragm. Passing under the seal of the trap the water rises on the other side and is discharged through the swan-neck outlet.

Each of the two side chambers is provided with an opening at the top fitted with a cover, and the wall of the gully has also a cleaning eye, fitted with stopper, giving access through the spout into the sewer.

Doulton's Borough gully is made in both circular and rectangular shapes, and in each form it comprises a catch-pit and an independent trap with a deep seal. When the catch-pit is emptied, the trap remains sealed, and there is consequently no need to recharge it with water to prevent the escape of sewer gas. The trap has a comparatively small surface of water, and it therefore does not become unsealed through evaporation in times of drought.

Both sides of the trap are readily accessible from the ground-level. An opening of ample dimensions affords access to the inlet side of the trap, and an inspection-eye provided with a galvanised iron sealing-plate, with tongue-and-groove joint, fitting into a fixed galvanised frame, permits the passage of a cleaning rod into the sewer.

When the catch-pit is emptied, water is retained in the trap, and the escape of sewer gas is prevented. The whole of the interior below the level of the weir is available for the accumulation of silt. In this respect this gully, with its high-level outlet, is a great improvement upon the ordinary type in which the outlet is low down in the gully and therefore liable to become choked by accumulation of sediment.

In a large city, it is very difficult to keep surface-water drains absolutely free of sewage, and unless constant supervision is exercised, house connections are made to them, especially if that drain is the most conveniently situated for the house-owner, and this is an additional reason for recommending that the water seal should

be so great. During the dry season it is a convenient plan to fill in all water gullies, right up to the grating, with clean sand : this allows of the road watering soaking through and passing into the drain, but prevents foul air from coming out into the street. In a general way, it is not necessary to arrange for the ventilation of surface-water drains, as, even though the first flow of rainfall may be very foul, it is usually followed by a much clearer liquid and the deposit in the drain is usually nearly all mineral matter which will not decompose.

Fig. 48 shews a drawing of a manhole on a surface-water drain.

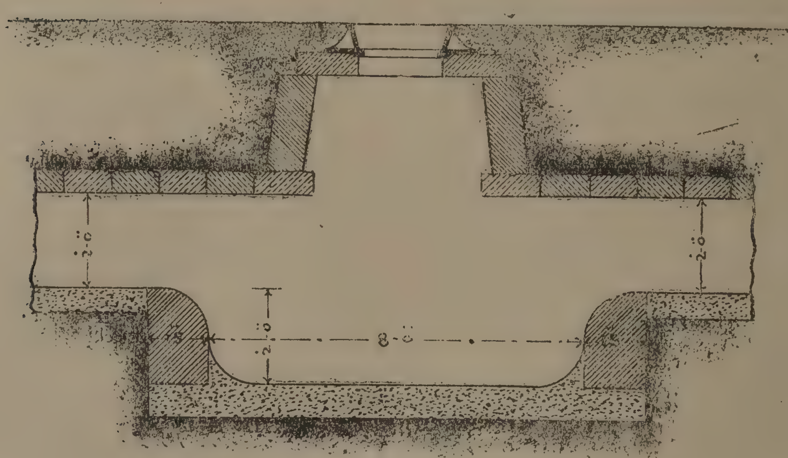


FIG. 48.

It has been found desirable to lower the floors of the manholes as shewn in the figure. They then act as catch pits, and facilitate the cleaning of the drain. The manhole is constructed of brick-work in lime mortar, 9 inches in thickness, the side walls resting on those of the drain and the end walls on the 6-inch dhapas. The whole of the inside of the brickwork is rendered with cement and sand (1 to 1) ½ inch thick. Galvanised Wrought Iron steps, as described, in manholes are inserted in one of the walls to enable the workmen to descend into the manhole. The manholes

are covered with the ordinary type of covers and frames shewn by Fig. 1 on Plate 4.

The cleaning of surface-water drains is usually done by hand and during dry periods. It is not accompanied by any danger from polluted air, and therefore the rules which apply to sewer-cleaning need not all be enforced.

Sub-Soil Drainage.—The question of sub-soil drainage, should always have consideration from the Sanitary Engineer, as the level of sub-soil water has much to do with the health of the community. The principal source of moisture in soil is rain, but it may arise from other causes, such as springs or excessive water-supply and wastage of the same. It is only when the sub-soil water is in excess and becomes stagnant and is close to the surface of the ground, that it becomes dangerous to health.

A saturated sub-soil prevents the circulation of fresh rain water through the soil, vegetation thereby losing the benefit. The effect of a wet or saturated soil is to reduce the temperature of the air, and is very often the cause of fogs; it is always the cause of mists arising from the ground, which are naturally injurious to health. A sub-soil of wet clay will shrink in drying about one-fifth of its bulk and swell again when wet, and for that reason buildings on such sub-soil should always have their foundations taken down below the reach of atmospheric changes: this depth in clay may usually be taken as 5 feet. Clay is a soil which is very retentive of moisture, and one cubic foot in most dry clays will absorb about one gallon of water. To get rid of superfluous water, sub-soil drainage is often necessary on sanitary grounds. If the sub-soil is composed of sand or gravel or loamy earth, then any liquid reaching the ground passes away by percolation, but this is not so in clay, which will take up moisture and retain it until it can hold no more, and any further supply of liquid remains or drains away on the surface if it can find an exit. A large proportion of the sub-soil in Bombay is clay overlying the basaltic rock and certain low-lying

parts of the Island are always wet, leading to much unhealthiness. The laying of drains and sewers generally has a beneficial effect in lowering the level of the sub-soil water, and provides a passage for it along the sides of the drain and the sewer. It is sometimes a good plan to put a layer of road metal around the drain or sewer for the sub-soil water to flow through.

The Author has sometimes found it useful to fix in the side walls of a surface-water drain flap pipes to allow of sub-soil water finding its way in; these pipes should not be placed below the springing line of an arched drain.

Sub-soil drains should not be less than four feet below ground level. Certain authorities recommend deeper drainage, and it is an undoubted fact that the deepest drains flow first and the longest. The filling in of old tanks is a question that crops up frequently in a large city like Bombay. Such tanks are often very deep and serve no useful purpose when a sufficient water-supply exists, but, on the other hand, they become the receptacle for all kind of rubbish and filth. Under these circumstances, they should be filled in with good clean earth and kept as open spaces; but a sub-soil water has always been flowing into the same according to the level of the water in them, in filling up such tanks a wall of coarse rubble or road metal, in which should be laid stoneware pipes with open joints, should be constructed all round the tanks, starting at a depth of 5 feet, that being about the depth at which sub-soil water ceases to be unhealthy, and the pipes graded to a point where a connection can be made with the nearest surface-water drain.

Wells abound in all large cities and their water unfortunately, no matter though it be greatly contaminated is preferred by many Hindus to the pipe supply. The watchful control of wells is an important Municipal duty, and Health Officers are frequently called upon to take action in regard to those that are a menace to public health.

The question of filling in wells is a fruitful source of friction between the public and the authorities, and no measure of equal sanitary importance is more keenly opposed. The fouler the well and the more necessary its filling in in the interest of public health, the greater generally are the demands that it shall be spared, usually on religious grounds. Although the most sympathetic and respectful consideration should at all times be given to the genuine religious sentiments of the people, a limit is often reached in sanitary matters, beyond which it would be the falsest kindness to go. Many wells are found on analyses to be seriously contaminated by sewage, and to allow such to remain and spread disease, as they inevitably do, is nothing short of criminal.

Before closing this Chapter, it may be interesting to allude briefly to the first portion of the scheme now being carried out for the surface drainage of the low-lands of the Island of Bombay. The area to be dealt with is equal to 2,865 acres. To drain this, a main channel has been constructed with a bed-level at its lower end at 71·50 T.H.D., or 6 inches below the lowest low water at spring tides. The bed slopes up from this level at a gradient equal to 2 feet per mile, and its capacity is based on a discharge of 0·70 cubic feet per second per acre, equal to 0·70 of an inch of rainfall per hour. The channel discharges into the Arabian Sea at the western foreshore of the Worli village, where sluices with four openings, each 20 feet wide have been constructed. The channel at the lower end is 62 feet wide at the bottom, with side slopes one to one, which are pitched with dry stones. It was originally proposed to pave the bed with dry pitching, and where the foundation is hard this has been carried out ; but for the main part of the channel 12 inches of lime concrete have been substituted, that having been found necessary owing to the soft nature of the ground. The main channel, which is known as Channel No. 1, runs from the Flats to Worli village and at a point near the old Worli sluices it bifurcates towards Dadar this branch being known as Channel No. 2.

It is proposed to continue the main channel by a covered drain at Jacob's Circle, and at that point it will receive various drains from different roads in the low-lands. The same procedure will be adopted in the Dadar District.

The cost of the main work, now in hand, will amount to 13 Lakhs, and it is at present very nearly completed. Plate No. 57 shews the position of the channels by a thick black line. Since the above was written the work described is completed and been found successful.

PART II.

INTRODUCTION TO PART II.

The following accounts of the drainage of various cities in the East will, the Author hopes, be found of value to the Sanitary Engineer.

In the matter of sanitation, Bombay stands out as a pattern of good local self-government, for there is no city in India, and possibly in the East, where such strides have been made in sewerage and in sanitation generally.

Most of the cities dealt with shew progress in sanitation, even from an occidental point of view ; and in most, as in Bombay, the completion of the sewerage system is progressing.

Since the above was published, several towns in Egypt have either prepared schemes of drainage or in some instances carried them out.

The sewerage works for Cairo and Port Said have been completed from the Author's designs and his plans for Tantah have been partly carried out and a scheme has been prepared for the drainage of Mansourah.

A scheme has been prepared for Alexandria by the late Municipal Engineer, Mr. Lloyd Davis, M.Inst.C.E., and only awaits funds to be completed.

All these works are described.

In the subsequent chapters dealing with towns and cities in the East, where additions have been made since 1906, the Author has through the courtesy of the engineers concerned been enabled to add details.

CHAPTER X

Cairo Main Drainage

THE City of Cairo stands on the East Bank of the river Nile, some 200 kilometres South of Alexandria and 170 kilometres south-west of Port Said.

The question of effectually draining the City had, according to such records as are available, occupied the attention of the Ministry of Public Works since 1885 On the 27th January 1885, the Ministry of Public Works nominated a Commission, which was known as the "Commission d'Assainissement du Caire." The work entrusted to the Commission comprised the study of all the questions relating to the health of Cairo, and the best means of ameliorating the sanitary conditions of the city.

The Commission, in acknowledging the necessity of providing a drainage system, pointed out that any proposition submitted ran the risk of being impracticable, should it be desired at a stroke to change the long standing habits of the people.

At that time, there were only 7,700 metres of ancient masonry storm water drains in the City, with three separate outfalls, of which no plan now exists. The Commission examined these drains, and recommended that the system be extended, and the existing outfalls intercepted and picked up by new collectors, which should discharge on to uncultivated lands in the vicinity of the city where the water could be used for irrigation. It also insisted upon the existing drains, and any extensions, being used only for storm water and sullage, the sewage from W. Cs. and urinals being excluded. In order to ensure this, the Cosmmissiour suggested that Government should formulate bye-laws.

The next step taken by Government was in 1889 when Mr. Baldwin Latham was asked to prepare a scheme for the drainage of Cairo.

In 1890, he submitted a scheme which included the areas of the City South of the Ismalia Canal and the district of Boulac. The scheme provided for laying hydraulic mains varying from 2″ to 6″ in diameter connected to 28 sectional stations, each containing hydraulic pumps in duplicate, the hydraulic power was to be supplied from a central station, situated near the Kasr el Nil Barracks. The diameter of the sealed sewage main proposed varied between 10″ and 36″ and was to have been laid through the Khalig and from thence to a sewage Farm situated outside and North East of the City.

The scheme was based on a population of 500,000 and an average consumption of 22½ litres per head per day for a lower class population of 400,000 and 136 litres per head per day for 100,000 better classes. These figures were equal to a dry weather flow of 22,600 cubic metres per day but Mr. Baldwin Latham provided for dealing with a total of 65,455 cubic metres per day, in order to allow for storm and infiltration water. The total area embraced by the scheme was 2,500 hectares, and though no direct figure is quoted in the report, an average rate of 1 person per 50 square metres of the City was the figure adopted. The rainfall reaching the sewers was equivalent to 17·14 m.c. per hectare per day or 1·7 m.m. of rainfall in 24 hours.

The capital cost was estimated at £E. 565·700 which figure included a sum of £E, 51,480 for supervision and contingencies. The annual working cost, with the water obtained from bores, was given at £E. 47,680,—and included an amount of £E. 32,968,— for interest at 5 per cent. and amortisation in 40 years of the capital cost. This proposal was submitted to a Commission who decided that before anything could be done, a much more detailed c heme was required.

The Government, therefore, resolved to hold an international competition, and a notice to this effect appeared in the *Official Journal* on the 2nd of January 1892. In response, 30 competitive designs were submitted, all of which were referred by Government to an International Commission comprised of one English, one French, and one German Engineer. The Engineers nominated were Mr. Henry Law (English), M. Guerard (French), and Herr Hobrecht (German).

The Commissioners were asked by Government to select the scheme they considered most suitable, and were at liberty to modify the accepted design as far as they judged necessary or in the event of their rejecting all, they were asked to submit a project which should, before presentation to Government, have the unanimous consent of all the members. Should this be found impossible, and a difference of opinion arise on the scheme submitted by the Commission, the Government were to appoint a Belgian Engineer as a final Arbiter.

The Commission, after examining the 30 schemes received, reported that they were unable to recommend any one of them for adoption, for the reason that none of the schemes had been sufficiently prepared, the period allowed for the submission of the plans being only one month.

The Commission were in possession of a report from Mr. J. Barois, who, after criticising Mr. Baldwin Latham's scheme, suggested that the only system suitable for Cairo was a "Combined System" by gravitation with one Main Pumping Station. This proposal obtained the full sanction of the Commission, who, in their report to Government, laid down the general lines of the scheme to be followed.

The Commission stated that beyond laying down the broad lines of the scheme, they were unable, to prepare any details owing to the lack of time and means, and suggested that the Government should appoint an Engineer and staff to do the necessary levelling, surveying, and detail work to complete the project and estimates.

The report of the International Commission was approved by Government, and Mr J. Barois was appointed to undertake the preparation of the project on the broad lines laid down by the Commission, and given authority to engage the necessary staff. The project was accordingly prepared and, after having received the approval of all the members of the International Commission, was submitted to the Ministry of Public Works on the 1st December 1893.

This scheme, to cost £E. 1,101·000, was approved by Government, and the specification and detailed plans were prepared. But strange to say, the whole matter was abandoned and nothing further was done. The reasons for this decision do not appear to have been recorded.

Between the years 1898 and 1899, three other schemes were prepared by Mr. now Sir William Willcocks. The last scheme, which was the one eventually approved, consisted of two main collectors, the one starting at the extreme south end of Cairo, and running down the Khalig and discharging at Pont Ghamrah, and the second being laid along the Ismalia Canal, and joining the Khalig Collector when both were to be prolonged for 360 metres to the Main Pumping Station. The sewage was then to be raised and pumped to a Farm. These two collectors allowed for the gravitating of 1,000 hectares out of a total area of 1,761 hectares; the remaining 761 hectares were to be dealt with by 12 compressed air ejector stations, each containing the necessary size of ejectors in duplicate.

The scheme included the construction of 500 public latrines and 255 kilometres of sewers.

The surface water was to be treated by providing 600 percolating and decanting wells, sunk at all low levels in roads and connected by an overflow to the neighbouring sewer. The overflow was to be controlled by a valve in order to control the flow of water into the sewer. The wells were to be 5 metres in diameter and carried down to below the subsoil water level. The average capa-

city of each well was placed at 40 m.c., giving a total storage capacity of 24,000 m.c. throughout the City.

The whole scheme was estimated to cost £E. 660·00 and the work was to be spread over 5 years. The running and maintenance expenses of the scheme and latrines were estimated to cost £E. 78,000 annually. This includes a sum of £E. 26,400 for interest on capital and amortisation over 66 years at 4%.

This was the first scheme that deviated from the lines laid down by the International Commission in so far that the question of dealing with the storm-water was considered on the separate system; but after having been approved, it was dropped and nothing further was undertaken until 1902, when some 8,000 metres of surface water drains were laid by the Tanzim Department to deal with the flooding of the streets in the better class quarters of the City, and these drains will be referred to later as they have been extended and made to serve as the basis of the surface water drainage of Cairo.

In October 1906, the author, who was then engaged on the Drainage of Bombay, was appointed by the Egyptian Government to prepare a project or projects for the drainage of the City, and to supervise the carrying out of the approved scheme. By the end of 1907, 11 alternative projects had been submitted, but it is not proposed to deal with any but the scheme approved and being carried out.

It was found that the only suitable plan available was to a scale of 1: 4000. When the main features of this survey were checked, they were found to be so inaccurate as to necessitate a triangulation, from which fairly accurate 1: 2000 plans were drawn up and subsequently used for contract drawings.

The drainage boundary (Plate No. 59) comprises an area of 3,052 hectares. According to the census of 1907, the city had a population of 644,000, the total annual water supply in 1906 being 18,808,778 metres cube, 9,000,000 metres cube of which was unfiltered and will not find its way into the sewers.

The sanitary conditions in Cairo in 1906 were very defective as, owing to the absence of sewers, the most modern of hotels, residences and flats were compelled to deal with their sewage by means of underground cesspools and soakaways. These works, in addition to causing a large initial expenditure, frequently required to be extended by additional soakaways, the old ones clogging in a short time. Further, landlords were compelled, owing to the entire lack of open spaces on their properties, to build the works inside the buildings, and were not able, when failure of the soakaways occurred, to extend them. These difficulties were the means of bringing into existence several companies, some of which tried to remedy the defects by sinking bores to depths of 40 to 60 metres, but without doing more than affording temporary relief.

Rainfall.—The meteorological returns compiled by the Survey Department show that the average rainfall in Cairo for the last 11 years is 23·50 m.m. the maximum and minimum for any one year being 51·10 m.m. and 4·10 m.m. respectively. During the above period there have been only eight occasions when the rainfall for any one day has exceeded 10 m.m. and, on three of these, more than 20 m.m. were recorded, while the maximum was 24·60. The total area of the scheme is 3,052 hectares and includes Cairo and suburbs, 2,602 hectares of which represents the City proper.

The City contains 4,300,000 square metres of roads, only 2,300,000 of which are macadamised or paved, the remaining 2,000,000 square metres being earthen roads, with very porous surfaces. The total unbuilt area is approximately 300 hectares and comprises public and private gardens. Further, the buildings being all flat roofed, hold up the major portion of the rain which is evaporated in the course of a few hours and can never reach the sewers.

The maximum rainfall, 25·60 m.m. in 24 hours, gives a rate of 3 litres per second per hectare, and after an allowance for evaporation, soaking in unpaved roads, unbuilt on areas, deferred flow,

etc., an allowance of 1 litre per second per hectare was taken as being sufficient to provide for.

Subsoil Water.—The level of the subsoil water is important, as the disposal of water pumped from the excavation presented great difficulties, due in many quarters to the absence of drains and in others to the inadvisability of discharging into the Nile too large a volume of sewage contaminated water.

For observation purposes, nine 3-inch steel lined bores were sunk in various parts of the City to a depth of 10 metres after striking water; it was thus ensured that the varying results of sounding were due to rise or falls in the natural underground stream, and were not caused by flooding of neighbouring sewage soakaways. The highest and lowest water levels obtained in boreholes No. 2 Saida Zeinab, No. 4 in Kolali, No. 6 in Abdine, and No. 8 in Shoubrah, represent the variations obtained from North to South of the City, and the results are given in the following table :—

Locality.	Borehole No.	Highest Recorded Level.			Lowest Recorded Level.		
		1907.	1908.	1909.	1907.	1908.	1909.
Saida Zeinab	2	Dec. 16·80	Dec. 17·30	Nov. 17·45	July. 16·10	July. 16·00	July. 16·40
Kolali ..	4	Oct. 16·50	Oct. 17.50	Filled in.	July. 14·75	July. 14·80	July. Filled.
Abdine ..	6	Dec. 16·75	Dec. 17·25	Dec. 17·45	July. 15·85	July. 15·90	July. 16·30
Choubrah ..	8	Oct. 16·30	Nov. 17·30	Oct. 17·45	July. 14·20	July. 14·40	June. 14·55

NOTE.—Reduced levels are all in metres above Mediterranean mean Sea Level at Alexandria.

These results, in addition to being a guide for fixing the depth of excavation in the lower part of the City, also fix the period of the year in which work could be undertaken most economically.

Geology of Cairo.—The Geology of Cairo is very irregular and variable, but falls into two main divisions (*a*) *Nile Mud*,

which is physically a highly plastic clay, but in its composition may be in many cases an extremely fine sand. (*b*) This is underlain by a thick series of sands, usually micaceous and fine textured in the upper layers, but having coarser bands containing large pebbles at great depth.

The depth of sewer excavation was limited to 5 metres below ground level in all streets, 10 metres and over in width, and three metres below ground level for streets less than 10 metres in width. The maximum depth of 5 metres applies generally to the European or better class quarters of the City, where the average reduced level is 19 metres and the depth of 3 metres in the poorer or native quarters, where streets are narrow and house foundations faulty.

Domestic Water Supply.—The fixing of the quantity of water consumed presented some difficulty owing to the cosmopolitan nature of the better class quarters, and to the habit and practices of the native and foreign population inhabiting the poorer quarters.

The population in 1907 was 644,000 for Cairo, and 14,000 for Zeitoun and Suburbs; of this former figure, some 50,000 were European and 50,000 higher class and educated Egyptians, who consume the same amount of water as the Europeans. These two classes were grouped and classed as upper classes occupying "Class A" houses and the remaining 544,000 was sub-divided after a detailed inspection as inhabiting houses of "Class B" and "C."

There were thus the following three classes of houses :—

Class "A"—Houses having an internal water carriage system and connected to the Water Company's mains.
,, "B"—Houses of a good class not connected to the Water Mains.
,, "C"—Sun burnt brick houses of inferior construction and "eshe-shes."

The class "A" houses are those that will be connected to the sewers in the ordinary way, and fitted with modern conveniences. The quantity of sewage to be expected was obtained by investi-

gations in the Upper class quarters of the City and fixed at 150 litres per head per day.

The houses of Class "B" were those found to be occupied by lower class people who purchased the water required for potable purposes from "bornes fontaines". There are many of these "bornes fontaines" or stand pipes in the City, and as inhabitants deal with particular "fontaines," definite boundaries were fixed, and the water consumption in these houses was found to be 10 litres per head per day.

The internal sanitary installations of houses in class "B" consist of a percolating pit inside the house, to which is connected a closet, without a flush, which also is made to serve as a slop sink. It was also found that practically all the adult male inhabitants of these houses resorted to the latrines attached to the nearest mosques, and this necessitated further enquiries into the number of people so making use of Mosque latrines, and the amount of water used.

An examination of 352 mosques was undertaken, and in each case the number of persons using the latrines and the amount of water consumed was obtained.

It was found that out of the 352 Mosques, 259 obtained their water supply from their own wells, and were used by 124,500 people, whilst the remaining 95 connected to the Water Company's mains were used by 25,500 people. The total number of persons using these mosques in 1907 was, therefore, 150,000 per day and the average water consumption was estimated to be 20 litres per head per day.

Houses in Class "C" are mostly on the outskirts of the town, and the inhabitants obtain the water required for domestic purposes from free "bornes fontaines" or the Nile, and only carry the amount actually required for potable puposes. The ablutions of these people are carried out in the open, and no sink or other convenience is provided in the houses. These houses are rapidly disappearing, and will, in a few years, be replaced by Class "B'

houses, and the inhabitants will be classified among the lower class population. The population of Class "C" houses in 1906 was negligible, so that the lower class population is estimated to include these.

The water supply from the above sources was as under :—

WATER CONSUMED PER DAY IN 1906.

			M.c.
Class "A" Houses,	100,000	@ 150 litres	15,000
Classes "B" and "C"	544,000	@ 10 ,, ...	5,440
Mosque latrines using water mains ..	25,000	@ 20 ,, ...	500
			20,940

The supply in 1906 was 18,808,778 m.c. per annum out of which 9,000,000 m.c. was unfiltered and not used for domestic purposes, thus leaving an average daily supply of 26,874 m.c. Out of this, 20,950 m.c. was accounted for by private consumers and the remaining amount used as under :—

		M.c. annually.
1.	Existing public latrines	118,208
2.	Railway latrines	478,813
3.	Army of Occupation	363,500
4.	Ministry of War	171,750
5.	Public Administrations	702,375
	Total ..	1,834,646

= Per day 5,025 m.c.

The total water supply, as far as could be ascertained, was therefore 25,975 m.c. per day, and that was taken as the quantity of sewage available in 1906. The differences of 899 m.c. is probably explained as leakage from water mains, and to the water supplied having been calculated on the running of the engines.

The foregoing details referred to the City proper, but Zeitoun and suburbs, which contain villa residences and flats required separate investigation. The average consumption of water for domestic purposes was found to be 100 litres per head per day,

and was due to the inclusion of servants who reside on the premises and were not large consumers of water for personal uses.

Having examined the habits and conditions that prevailed in 1906-1907, the author was surprised to find that the average quantity of water consumed per head of the total population of Cairo was only about half that of Bombay.

The works are designed for a prospective population at the end of 25 years or in 1932, of 960,000, say 1,000,000, and this was estimated by examining the possible extensions in each kism, or district, in order to ascertain if the proportionate increase of census figures for 1897-1907 could be maintained in the future. The percentage of increase of population between 1897 to 1907 was given at 14·80% in Cairo for all nationalities. The increase adopted on the lower class population for the period 1907-1932 was 43% for the 25 years at 15% per 10 years, allowing a small percentage over that established by the census.

A decennial increase of 34% for Europeans was established by the census, and presented special peculiarities which had to be taken into consideration under two heads (1) Influx due to Tourists, and (2) Permanency of residence of European immigrants. The first of these factors was found to be negligible, as the consumption of water was appreciably less during the winter months and tourist season than in the summer. The second factor was influenced by the Southern European races, about half of whom mixed with the indigent population, inhabited houses, Class "B," and generally lived like the lower classes, the other half being classified as Upper Class.

Of the total increase of 34% in the decennium 1897-1907, half or 16% of whom had been classified in the lower class population, so that 18% was the estimated rate of increase for the upper European classes, and this figure was increased to 20% to include the Upper class Egyptians.

The daily water supply accounted for in 1906 was 25,975 m.c. on a population of 644,000, or 40⅓ litres per head per day, including all public administrations.

In drawing up the table of water consumption for 1932, the sources of supply to Government were carefully considered because of the great expense entailed in purchasing water from the Cairo Water Company at a rate of 2*d*. per m.c. It was decided that 400 public urinals and latrines would be needed throughout the City and placed in convenient centres to serve the lower class population, and further that 300 automatic flushing tanks would be needed at the heads of certain sewers.

Owing to the congested state of the native quarters, and the difficulties of acquiring suitable open sites, it was decided that the Wakfs Administration should be asked to place the land already occupied by mosque latrines at the disposal of the Government, the latter undertaking to defray the expenses of converting the building into public conveniences, installing an up-to-date water carriage system and connecting them to public sewers. This was agreed to at a later stage, and some 100 mosque latrines were selected as being suitable for conversion. This system should work well, as the mosque latrines have, for generations, served the public of all denominations and creeds who live in close proximity to these places.

The following table was drawn up and allows for a prospective consumption in 1932 of 50 litres per head per day as being the minimum volume required for a satisfactory water carriage system.

TABLE GIVING PROSPECTIVE POPULATION AND DAILY AMOUNT OF SEWAGE IN 1932.

Items.	Source.	Population.	Rate litres.	Total sewage m.c.
1	Upper Classes	160,000	150	24,000
2	Mosques	215,000	20	4,300
3	Latrines and Urinals	565,000	10	5,650
4	300 flushing tanks at the heads of pipe sewers	....	1,000	300
5	Zeitoun	20,000	100	2,000
6	Collecting Chambers and Gullies allowing 15 litres approximately per head per day on population in items 2 and 3 ..	....	....	12,000
	Total ..	960,000		48,250

Of the whole area embraced by the scheme, Plate No. 59, 731 hectares are drained by gravitation into the Main Collector and 2,321 by the sectional system. These areas are coloured pink and green respectively on the plan. The surface water from a large portion of the City drains to existing surface water drains, with an outfall at the Pumping station in Chareh Abbas. Further small areas are drained of surface water to the Nile by gravitation, whilst the districts between Abbassieh and Matarieh are, by the contour of the ground, drained of surface water to the Gebel Canal. The rain water in other parts of the city is treated on the combined system.

For the drainage of the area on the sectional system, 63 ejector stations, in cast iron tubbings, have been installed, each tubbing containing duplicate ejectors. The compressed air is supplied through cast iron mains from the air compressing station in Sharia Abbas, the sewage being ejected through cast iron sealed sewage mains and discharged into a chamber at the head of the main collector at Ghamrah. This chamber is at the commencement of the collector which is 1·60 metres in diameter, 13·670 kilometres in length, and has a gradient of 1 in 2,500. The sewage from this collector discharges through the screening chamber at Kafr el Gamous into the sump under the engine house, and is then pumped through a cast iron main 11·150 kilometres in length to the purification works at Gebel el Asfar. Here, it passes through hydrolytic tanks and filters, and is used for irrigating 3,000 feddans of land which have been reserved as a farm.

Surface Water Pumping Station Sharia Abbas :—Plate No. 60 shows the areas that were intended to be drained on the separate and combined systems. The area coloured blue, amounting to 340 hectares, had already been drained by the Town and State Buildings Department to the outfall A, where the surface water was pumped into the Ismailia Canal. These drains were examined, and it was decided to extend the system to include a further area of 460 hectares coloured yellow on the plan, and lying to the east

of the present catchment area and the Boulevard Mohamed Aly, and to instal a new surface water pumping station with machinery capable of dealing with a minimum flow of 40,000 cubic metres in 24 hours, any excess owing to the high state of dilution being discharged into the Nile through the Ismailia Canal.

The surface water from the Roda Island and from the strip coloured pink adjoining the Nile from Old Cairo to Embabeh Bridge was to be drained into the Nile, as also the strip of land coloured brown on the bank of the Ismailia Canal which was to be treated in the same way. The remaining parts of the city that could not be drained either to the Nile or to the Ismailia Canal were to be treated on the "combined system," Zeitoun and suburbs were to be dealt with on the "separate system," the surface water being allowed to drain along the roads into the Gebel Canal.

Under the above proposals, there were 1,721 hectares including Zeitoun and suburbs, drained on the "separate system" and 1,321 hectares on the combined system.

This scheme was approved, and the works were commenced in 1909. During the progress of the undertaking, Government decided to fill in the Ismailia Canal, and an ovoid culvert (1·00 metres × 1·50 metres) was constructed in the bed to serve in place of the open canal. Towards the end of 1910, when the works were about half finished, and the three storm water discharges required for draining Old Cairo, the Garden City and the Ismailia Quarter had been installed, the discharge of surface water into the Nile was forbidden, this decision being due to the Cairo Water Company having been permitted to draw the water supply for the city from the Nile down-stream of the surface water outfalls.

The lines of the original scheme were then altered, the contract was closed and a succession of overflows to various ejector stations were installed, so as to divide the work of pumping the surface water drainage amongst several ejector stations. Should a very heavy rainfall occur, the outfalls, as constructed, can be brought into operation by opening the penstocks which control the dis-

charges into the Nile. The outfall drain, leading to the Ismailia Canal on the old system (coloured blue) had a calculated maximum discharge of 68,000 cubic metres per 24 hours, and this system was extended by laying drains in the Sharia Mohamed Aly, Mousky and the principal adjoining streets that were asphalted or macadamised, and at such levels as to allow of laying future drains in the whole of the area coloured yellow.

The actual works included the laying of 23,160 metres of stoneware pipes varying in diameter from 21 to 9 inches, and to these were connected some 800 street gullies. All drains, with the exception of the Garden City and Old Cairo, gravitate to the surface water pumping station constructed in Sharia Abbas, where the invert level of the outfall drain is 15·577 metres, or exactly 5 metres below ground level. The sewage is received in a sump 15·70 metres in length by 2·39 metres in width, with the bottom at R. L. 14·22; from here a 16 inches diameter cast iron pipe leads all the surface water to ejector station No. 25 S.W.D. which contains two 500 gallon ejectors in a cast iron tubbing. These ejectors are designed to deal with at least 1,000 gallons per minute or 6,480 meters cube per day, and one ejector is sufficient to deal with the street and market washings amounting to 3,500 meters as a maximum. As soon as the flow is in excess of the capacity of the two surface water ejectors, the water rises in the sump and after passing through screens, is admitted into the adjoining secondary sump, contained under the pumping station building and each 1·70 meters wide. The entrance to these three secondary sumps are controlled by penstock weirs each 1·20 meters wide. The first secondary sump contain the suction of a 12″ by 12″ ram pump. The second receives the suction of a 14″ diameter horizontal centrifugal pump whilst the third serves the suction of an 18″ diameter horizontal centrifugal pump.

The 12″ by 12″ ram pump discharges, as a temporary measure, on to the desert near Abbassieh, and was installed in 1912, when the new water supply intake was constructed below the City. This

arrangement is now suppressed, and the remaining two pumps discharge the water normally into a 30 inch gravitation main in Sharia Abbas to the Chamber at the head of the Main Collector at Pont Ghamrah.

A 24 inch cast iron emergency main is also provided and this directly connects the two centrifugal pumps to the Chamber at Pont Ghamrah where a bye-pass has been provided to pass the flow, should necessity arise, into the Ismailia Canal. In case of a sudden and extraordinarily heavy storm, an overflow has also been provided in the sump which will allow of the surface water flowing into the Nile through the culvert laid in the bed of the old Ismailia Canal.

The sumps and pump chamber are constructed in concrete as also are the foundations of the engine house, the floor of which is carried on steel girders and jack arches. The superstructure is in red Sornaga bricks, and Bassatine cut stone and roofed over with Marseilles tiles.

The pump machinery consists of 3 pumps and two 500 gallon capacity compressed air ejectors, the total output of each being as under :—

12″ × 12″	ram pump	..	3,300	cubic meters	per	day.
14″ Centrifugal	,,	..	18,325	,,	,,	,,
18″ Centrifugal	,,	..	39,270	,,	,,	,,

The 14 inches and 18 inches centrifugal pumps are of the vertical spindle low lift centrifugal type, having central suction openings and closed impellers. They are placed below the water level in the sump in order to be self-charging, and are driven by vertical spindle electric motors placed on the floor above.

As the actual lift is small, about 10 feet, the friction head on 2,500 meters of rising main is the more important factor, and it was, therefore, impracticable to instal the 18 inch and 14 inch centrifugal pumps so that either or both could be worked together. The 18 inch pump is, therefore, arranged to deliver against a head corresponding to its greater capacity, and the pumps are never worked together in the same delivery main.

The 18 inch centrifugal pump is capable of delivering 6,000 gallons per minute against a head of 60 feet, and is driven by a 165 H.P. motor, whilst the 14 inch centrifugal pump can deliver 2,800 gallons per minute to a head of 15 feet, and is driven by a 25 H.P. motor.

Both centrifugal pumps are direct driven, and coupled to the motors with flexible couplings, the weight of the shaft being supported on ball bearings. The pump casings are of the volute type, fitted with diffusion chambers; the whole of the interior being arranged by means of suitable hand holes for easy inspection; the impellers are of hard phosphor bronze.

The 12 inch × 12 inch ram pump is of the vertical three throw, outside packed plungers type, driven by an electric motor mounted on a combined base plate through two pairs of helical gear wheels. Its capacity is 500 gallons per minute delivered against a head of 300 feet.

The electric motors are of the induction type, driven by single phase alternating current of 40 periods per second.

They are built with wound Motors, with a running and starting phase, each being arranged with a choke coil which, when starting, is connected in series with the starting phase and cut out on the motor attaining full speed.

The current is delivered to the Station at a pressure of 2,000 volts and is used at this pressure for driving the 165 H.P. motor. For the two smaller motors, the pressure is reduced by a step-down transformer to 400 volts.

The transformer is of the usual oil immersed type having a capacity of 90 kilo-volt-amperes.

The switch board consists of four panels of enamelled slate, one panel for each of the motors and one for the transformer. Oil switches are provided on all the high tension mains, and automatic contact breakers are provided where the leads enter the building and also on each motor.

Sewer Reticulation.—The laying of the sewers was considered on the basis of the immediate requirements of the City, and the sewer reticulation is designed to allow of sewers being laid in all streets where properties exist that are either public buildings, houses containing a water supply from the Water Company's mains, or mosques. The houses in the European quarter are practically all supplied with water from the Company's mains, but in the native quarters, a detailed survey of houses had to be undertaken to ascertain the streets to be sewered.

The scheme of reticulation for the sectional areas will require 256 kilometers of street sewers varying in diameter from 9 inches to 7 inches and 37 kilometres of 5″ street connections for connecting up 9,500 properties.

The general rule fixed for the laying of sewers is that the maximum depth of excavation is not to exceed 5 metres or 3 metres, according to the width of the street, and that all sewers are laid at gradients giving a velocity of $3\frac{1}{2}$ feet per second when flowing half full. The manholes are conical, and constructed of locally made bricks, laid on a 0·35 metres bed of cement concrete. The pipes below R.L. 17·50 metres are principally "Keeptites", to allow of a good joint being made in wet ground and all pipes above this level are of the true invert type. Flushing tanks are placed at the heads of main lines of sewers, and the shorter lengths are to be flushed periodically by water carts or hydrants. The sewers in ejector areas that are on the combined system will gradually be provided with street gullies, the sites being chosen and the gullies fixed at points that are flooded during wet weather. A locking plate arrangement has been devised in order to prevent people making use of the gullies as dust bins, and is easily removable by means of a special key supplied to the man in charge of street cleaning operations.

The ventilation of sewers is to be carried out through the house drainage, and no intercepting traps are to be provided. Further, n order to avoid the flooding of streets, etc., the head sewers of all

ejector areas are connected together at a common manhole placed on the boundary of adjoining areas.

Compressed Air System and Air Compressing Station Chareh Abbas.—The drainage of the low-lying portion of the City is on the sectional system, worked by compressed air for which 63 ejector stations have been sunk in the positions shown on the plan. Each ejector station consists of a cast iron water tight tubbing of sufficient diameter to contain two and in two cases three, ejectors of the size required for lifting the sewage of each area. The capacity of the ejector is calculated on the maximum dry weather flow per minute from the area served, and the second or duplicate ejector is always provided to act as a stand by in case of repairs or unforeseen contingencies. Where the area is drained on the combined system, the maximum wet weather flow is taken, and the capacity of each ejector is half that of the maximum wet weather flow per minute.

The tubbings for ejectors were sunk, where conditions permitted, in open cutting, but in places where the subsoil water level was high and the flow abundant, an air lock was used and the tubbing sunk under an air pressure of about 10 lbs. per square inch. The tubbing was manufactured in segments, which were erected *in situ*, and the joints made water tight with lead packing. The floor consists of cast iron segments bolted together and stiffened with girders concreted over.

The ejectors in use are of the Shone and Ault pattern, the smallest station being fitted with 50 gallon ejectors in duplicate and the largest with three 500 gallon ejectors. Of the total number of stations, 14 are fitted with duplicate 50 gallon ejectors, 14 with duplicate 100 gallon ejectors, 10 with duplicate 150 gallon ejectors, 16 with duplicate 250 gallon ejectors, 1 with duplicate 300 gallon ejectors, 5 with duplicate 500 gallon ejectors, and 3 with 500 gallon ejectors in triplicate.

All ejector stations are entered from the top except in two instances, *viz* :—Nos. 33 and 37. Ejector No. 33 is in the Ezbekieh

garden, the principal public garden of Cairo. At this ejector station, the cast iron tubbing has been enlarged and lined with white tiles, and a spiral staircase gives access to it from the ground level. It is surmounted by an ornamental building in brick and stone and is open to inspection by the public.

Ejector Station No. 37 is situated in the Mousky, the busiest street in Cairo, and a side entrance has been provided in this case in order to facilitate inspection and avoid interference with traffic.

The sewage is raised from the ejectors by compressed air, which is supplied through cast iron mains varying in diameter from 14 inches as a maximum to 2½ inches as a minimum. The air mains are laid in circuits, and controlled by air valves to ensure a continuous supply, should a rupture or leak necessitate the shutting down of any particular length. They are also fitted at low points with draw-off taps for removing the condensed water from mains. These condensed water draw-offs consist of a U tube which is tapped into the main at its invert, and is carried up to the surface of the road and fitted with a tap through which the condensed water, by virtue of the air pressure in the main, is expelled in the street. The exhaust air is discharged from the ejector into a silencing chamber consisting of 24 inches diameter cast iron pipes connected to a ventilation column 11 metres (35 feet) in height, and varying between 9 inches and 12 inches in diameter. The silencing chamber is laid at a gradient, and any moisture carried on by the exhaust air is drained back to the inlet manhole through a 1½ inches diameter galvanized iron pipe. The pipes used are 12 feet long of the ordinary spigot and socket pattern, and 1, 2 or 3 pieces were used according to the capacity of the ejector station; the pipe ends being blocked up with concrete, the exhaust pipes from ejectors and the connection to the ventilation column being placed centrally in the concrete mass.

All sewers and air mains have been laid with a minimum cover of 1 metre and have generally followed the surface levels of the

roads. Wherever possible, the air mains have been laid under pavements to avoid heavy traffic.

The compressed air is automatically supplied to each ejector on its being filled with sewage, and the contents are displaced and passed to the Main Collector through cast iron sealed sewage mains varying from 6 inches to 33 inches in diameter. It will be seen that there are three distinct arteries that serve the whole system, *i.e.*, Eastern or Khalig sealed sewage main, the Western or Sharia Abbas, sealed sewage main, and the Northern or Shoubrah sealed sewage main. The Khalig sealed sewage main starts from Ejector Station No.5 which station, in addition to serving area 5, re-pumps the sewage from ejector areas 1, 2, 3, 4, and 12, and is also capable of dealing with the sewage of Rodah Island. This main starts with a 15 inch cast iron pipe and is increased to 30 inches and finally to 33 inches before its junction with the head Chamber of the Main Collector. Before its discharge into the Main Collector, a 33 inch Venturi Meter is installed in an accessible chamber. The throat of the meter is submerged, a drop of 1·70 metres being allowed on a 50 metres break in the regular gradient of the main.

The Western, or Sharia Abbas Main, starts from ejector station No. 25 and re-pumps the sewage of Ejector Stations Nos. 23, 23A, and 23B. This main starts with a diameter of 14 inches and is again enlarged to 18 inches until it discharges into a 30″ gravitation main at Ejector Station No. 25 S. W. D. The gravitation main is laid at a gradient of 1 in 1500 and is enlarged from 30 inches to 33 ins. The diameter of 33 inches is maintained up to the 33 inches Venturi Meter which is installed for gauging the flow on this main. At this point, which is at the junction of the Choubrah main, the sewage is discharged into a 45 inch circular brick lined concrete culvert 283 metres long which carries on to the head Chamber of the Main Collector. A drop has been made between the invert of the 33 inch main and 45 inch culvert for submerging the throat of the Venturi meter.

The Northern, or Choubrah main, starts at Ejector Station 71 with a 9 inch pipe and is gradually enlarged to 15 inches after the junction of ejector stations 74, 77, and 78. On leaving the Choubrah road, the diameter of 15 inches is increased through varying stages and finally joins the chamber on the 45 inch brick lined culvert as a 33 inch cast iron main.

No Venturi meter has been fixed on this main, but provision has been made in levels for inserting this as soon as a meter is required in this section. Choubrah is not yet fully developed and the sewers in this area will be the last to be laid.

All sewage mains, 10 inches and under in diameter have been fitted with inspection openings at all bends and on every 200 metres of straight piping. These openings are for locating or removing any blockage, should such occur, and are 1 metre in the clear perfectly water tight, the cover being securely bolted down.

Sluice valves are provided at all junctions to enable any ejector station being cut off from the mains, and immediately outside all stations, a chamber containing a further sluice and reflux valve is provided.

The sealed sewage mains were tested to a hydraulic pressure of 50 lbs. per square inch, which pressure had to be maintained for 15 minutes without loss or visible leakage.

The tests for air mains consisted of applying an air pressure of 50 lbs. per square inch, which pressure was not allowed to drop below 45 lbs. during one hour.

The above tests were applied as each length was completed and the whole system was again finally tested on completion.

The positions of all sluice valves, air valves and inspection openings have been marked in the ordinary way by fixing cast iron indication plates on adjoining properties.

The air compressing or power station is situated in the Chareh Abbas, and as the ground was soft and yielding, it necessitated special foundations for the buildings and chimney. These were constructed on the "Compressed System".

The machinery at the Compressing station comprises four sets of compressing engines : four water tube boilers with their auxiliary pumps, an independent condensing plant, two electric generating sets and a small repair workshop.

Each set of compressing engines consists of a triple expansion steam engine and three single stage air compressors worked from the tail rods of the three cylinders, the whole together with the cross-head guides and main bearing pedestals, being mounted on a bedplate. The bed plates of each engine are bolted into a mass of concrete which is carried on a reinforced raft supported by 9 compressor piles.

The air is delivered into the mains at a pressure of 22 to 25 lbs. per square inch above the atmosphere, and each compressor is capable of compressing 1,770 cubic feet of free air per minute.

The compressing engines were manufactured by Messrs. Hughes and Lancaster of London and Ruabon, the Contractors for the Compressed Air System.

Steam is generated in four Babcock and Willcox water tube boilers, each having 1,426 square feet of heating surface fitted with superheaters capable of imparting 150 degrees of superheat to the steam.

Two "Weir" compound steam feed pumps are arranged in the boiler house for feeding the boilers and the water is heated by passing through a tubular economiser placed in the main flue outside the boiler house. The boilers are arranged for natural draught from a chimney 6 feet in diameter by 150 feet high.

The condensing plant consists of two surface condensors each of 1,100 square feet of cooling surface. The circulating pumps of the centrifugal type, and the air pumps of the Edwards type are both electrically driven.

The electrical power required for lighting the station buildings and driving the various motors is generated in two compound dynamos running at a speed of 400 revolutions per minute and generating current at 220 volts pressure.

The dynamo room is separated from the condensing room by a brick partition and the exhaust steam from the dynamos is received by the main condensors.

The cooling water for the condensing plant is taken from a cooling pond outside the building.

On its return to the pond from the condensers, it is cooled by passing through two centrifugal sprayers driven by electric motors.

A Venturi meter is placed in the return main from the circulating pumps, and measures and records the quantity of circulating water used by the plant.

The condensing plant and the electrical generators were manufactured by Meessrs. W. H. Allen Son & Co. of Bedford.

The compressed air from the Power Station is delivered into two wrought iron receivers placed outside the building. These receivers are each 8 feet diameter by 30 feet long and together have a storage capacity of 3,000 cubic feet. These receivers discharge into the mains through a Venturi meter which measures and records the output of compressed air from the Station. The principle of the Venturi meter for measuring the flow of air is exactly the same as that for measuring liquids. Pressure pipes are brought in exactly the same manner from the two points of the Venturi tube to the recording instrument. The only difference in the instrument being the extreme sensitiveness required to measure the exceedingly small difference of pressure due to the flow of compressed air. As the pressure of the air flowing through the metre is liable to vary, the recording mechanism is automatically corrected for pressure by a differential gear actuated by a "Bourdon" tube. The instrument is also fitted with a thermometer which records the temperature of the air passing through the tube, and the recording mechanism is arranged for adjustment to correct the readings to allow for the variation of the mean temperature. By this means an accurate record of the output of compressed air from the station can be kept.

The Venturi meters on the sealed sewage mains are both electrically connected to duplicate counters placed in the Power Station side by side with the compressed air meter, and a comparison of these meters shows at a glance any variation in the efficiency of the system.

The engine room contains a hand power travelling crane of 7 tons capacity which serves the main engine room, the dynamo room and the condensing room. A small workshop is provided in the main building equipped with several small machine tools driven by an electric motor for dealing with the repair work required on the Power Station.

Since the above was written the overall efficiency of the Pneumatic System from steam cylinders to ejectors has been officially declared by the Egyptian Government as 37·4%. The contractors' guarantee was 35% so that the specification has been exceeded. Considering the magnitude of the scheme this is so far probably a record.

Main Collector.—The main collector starts at Pont Chamrah, at which point a chamber is constructed to receive the 1·15 metre (45 inches) diameter brick lined culvert in the Sharia Abbas and the 0·84 metre (33 inch) cast iron main in the Khalig, both of which discharge at R.L. 15·09. A connection also exists in the chamber for the 0·61 metre (24 inches) diameter cast iron main from the Charia Abbas Surface Water Pumping Station.

The head chamber is constructed in cement concrete, with a flat concrete roof carried on girders, and the invert is brick lined to a height of 0·80 metres above the main collector invert, and access is provided through a manhole.

The main collector leaves this chamber at R.L. 14·668 metres, the ground level being 18·58 metres.

The collector, Plate No. 61, is 13,670 metres in length and 1·60 metres internal diameter and constructed of cement concrete for its entire length, except in the Koubbeh Avenue, where a special cast iron pipe with a flattened crown, of the same sectional area,

is laid in order to pass under an irrigation canal bed, the two railway crossings and a short length near a mosque at Pont de Koubbeh.

The gradient is 1 in 2,500 throughout, and the collector is capable when flowing half full, of discharging 55·15 cubic metres per minute with a velocity of 3 feet per second. The maximum future dry weather flow is calculated at 52·083 cubic metres per minute so that the collector will be practically flowing half full and a reserve space will be available for an additional 66.56 cubic metres per minute in the event of heavy and unexpected rain storms occurring.

It is constructed of cement concrete consisting of 5 parts of broken stone, 5 parts of sand and 1 part of Portland cement of local manufacture. The concrete is 0·44 metre thick at the invert, 0.45 metre at the sides, and 0·35 metre at the crown and a 0·30 metre reinforced concrete (Siegwart) sub-duct surrounded in dry rubble packing is laid to drain the foundations of the trench. During construction, it was necessary to increase the capacity of the sub-duct in the canal section, and two pipes were laid on either side of the centre of the collector. The excavation of the trench was taken out only to the full width of the concrete base, and in certain places where the excavation was in fine sand, the timbering was left in to ensure the sides of the collector being in contact with the undisturbed ground of the trench faces, and for this purpose, 3,800 cubic metres of timber was left in.

Along the whole length of the collector, 113 brickwork manholes have been constructed for inspection purposes and for making any further connections as further street sewers become necessary.

The ventilation is carried out by means of ventilation columns.

All connections for sewers from the gravitation area are made at spring level, or 0·80 metres above the invert of the main collector.

The construction works presented particular difficulties on account of the large volume of subsoil water that had to be raised from the trenches. Heavy and close timbering had to be employed,

as the soil consisted of sand that was difficult to keep back on account of the rate of subsoil water filtration. The average level of subsoil water along the route from the head chamber to the Gebel Canal was at R. L. 14·50 and at the collector outfall at R. L. 13·00, the difference being due to the greater distance of the latter point from the Nile. The general geological Section of the land along the route of the collector is simple, and consisted, between Ghamrah and the Obelisk, of a layer of black Nile mud 3 metres deep, beneath which was sand heavily charged with water. Beyond the Obelisk, from the point where the collector entered the Gebel Canal, the excavation was almost entirely in sand.

Screening Chamber, Sump and Main Pumping Station, Kafr el Gamous.—The main collector discharges at R. L. 9·20 metres and the sewage is received in a controlling chamber 9·60 metres × 2·40 metres, the floor level of which is 1 metre below the collector invert. This chamber is fitted with two penstocks, which allow of the sewage being passed into one or both of the screening chambers. The screens are composed of slightly tapered wrought iron bars spaced $\frac{5}{8}$ inch apart, and kept clear by rakes carried on endless chains driven by sprocket wheels. The rake teeth are arranged in groups of 12, to engage with the bars of the screens, and travel from the bottom upwards, being guided by suitable pulleys and rollers. The debris removed is carried to the surface by the rakes, where it is tipped automatically on to a hopper; the rake teeth are cleaned by engaging in a rotating rake situated above the hopper. The screenings then slide down the hopper into waggons and are transported away.

For the removal of heavy solids, detritus pits are placed immediately in front, and at the foot of the screens, the shape of the pits are shown on the plan and the detritus is dredged up to the surface by bucket elevators, the bottom of the pits being shaped to suit the sweep of the buckets. The buckets are made of pressed steel, 20 inches long by 8 inches wide, and 10 inches deep placed two metres apart and carried on endless chains, driven at the rate of

25 feet per minute and guided by sprocket wheels. The buckets are inverted by passing over a guide wheel on the head gear, where the contents are tipped on to a hopper from where it passes into waggons for removal.

The screen rakes and detritus elevator buckets are separately driven by electric motors through worm and spur wheel reduction gear, mounted on independent bed plates, and directly coupled to the driving shaft carrying the sprocket wheels. Electric current for power and for the lighting of the screening chamber is brought from the main switchboard in the main pumping station by overhead cables, and enamelled slate starting panels are fixed for controlling the 4 motors and the lighting.

The screening chamber is supplied with fresh water from the water tower in the main pumping station, and taps and hydrants are conveniently fixed to allow flushing of the hoppers and also for general cleaning and flushing purposes. Access to all parts of the controlling and screening chambers is obtained by platforms and ladders which are placed in convenient positions, and steps are also provided in the detritus pits.

The sewage, after having passed the screens, is received in a controlling chamber which is joined to the sump by means of a connecting duct. This chamber is fitted with two penstocks which allow of one of the screening chambers being cut out should need arise.

The foundation level of the screening chamber structure is at R. L. 5·15, the ground level being at R. L. 19·60. The walls are made of cement concrete, the bottom flooring being 3·20 metres thick and the upper 1 metre thick. The floor was laid after the walls were constructed, the excavation being removed by dredging. It is constructed of cement concrete 3·05 metres thick, except under the detritus pits, where the minimum thickness is 1·15 metres, and is bonded into the walls and reinforced by means of steel rails and girders, as the lifting pressure exerted by the subsoil water is equal to a head of nearly 8 metres. The level of the ground floor

of the screening chamber is at R. L. 19·725, and this floor is also composed of cement concrete reinforced by rolled steel joists.

The superstructure is carried on the screening chamber walls and is composed of brick work with artificial stone quoins roofed over with boarding and Marseilles tiles carried on steel trusses.

The connecting arm of duct is 66·30 metres in length, and leaves the screening chamber at R. L. 8·20 metres or 1 metre below the main collector invert, and discharges into the sump at R. L. 7·70. The sump is 53 metres long and 5·40 metres in width and contains 5 suction pits placed at R. L. 4·60 which receive the pump suctions; these pits are curved so as to allow of any solid matter being picked up by the pumps and ejected up the rising main. The floor of the sump between suction pits is graded to enable any solid matter not arrested by the screens to gravitate to the suction pits. The extreme depth of the sump is 6·48 metres measured from the lowest part to the underside of the arch, which is finished to a radius of 4·40 metres in cement concrete reinforced to carry the pumps. The pumps are placed immediately above the sump on a floor at R. L. 12·60 metres.

The whole of this floor is divided into 9 compartments, 5 of which are for the pumps and 4 for ventilation and lighting. All the compartments communicate and are lighted from the engine house floor by pavement lights. Above the pump chamber is the engine house which is at R. L. 20·80 metres and carries the engine bases, the fly wheels being let into recesses in the floor.

The sump foundation level is carried down to R.L. 5·00 and the ground level is at R. L. 19·60. The whole of the construction is carried out in cement concrete with steel girder reinforcement in parts.

The excavation was carried down in open cut to subsoil water level or to R. L. 12·60 and the sides above this level were sloped back to the natural angle of rest of the soil. Below R. L. 12·60 channel section steel piling was used entirely except on a portion

where the length of steel piles did not permit of work below R. L. 4·20. Here, internal wooden frames were used to complete the depth of cutting to R. L. 3·00.

The total excavation for the screening chamber and sump amounted to 23,626 cubic metres exclusive of slopes.

The flow of water at the higher levels was very great, and was further increased by two blows occurring in the sump foundations owing to the pressure exerted on the layer of clay by the subsoil water. This pressure was relieved in other parts of the foundations by sinking two bores through the clay, thereby tapping the water bearing sand below.

The excavation below R. L. 12·60 was carried out in two sections and as soon as the foundations level was reached in each section the concrete was laid and the side walls constructed, all necessary holes for bolts, pipes, drains, etc., being left in the positions and at the levels required.

As soon as the concrete in the sump foundations was laid, the great difficulties experienced in keeping the water down in running sand disappeared, and the construction was completed to R. L. 12·60 (the pump floor chamber level) very rapidly. At this point, the engine house foundations were started at R. L. 13·55 by excavating the slopes before referred to, so as to ensure the foundations resting on undisturbed ground. The width of the reinforced concrete base for the outer walls is 2·25 metres and its depth 1·00 metres.

The rest of the foundations are carried up in concrete to R. L. 19·00 or 0·60 metres below ground level, and the work above this is carried out in bricks and artificial cut stone work. The interior of the engine house is tiled with glazed tiles to a height of 3·20 metres above floor level, and the upper faces of the walls are rendered and enamel painted cream, with a freize of glazed tiles just below the level of the cut stone carrying the travelling crane. The roof is in steel, covered with tongued and grooved boarding and red Marseilles tiles. An iron storage water tank is placed on the roof

of each of the two towers for the supply of water for the installation and staff.

The engine and dynamo bases are fixed at R. L. 20·80 whilst the fresh water pumps are in a separate pump room at R. L. 18·05. This pump room communicates with a steel floor placed at R. L. 16·40 which allows of inspecting the condensers and communicates with the main pump chambers. Under the steel floor is a passage at R. L. 14·875 in which are laid the circulating water pipes, etc.

Main Pumping Station.—The machinery at the Main Pumping Station (Plate No. 62) has been supplied by Messrs. James Simpson & Co., Ltd., of London and Newark. It comprises four direct acting plunger steam pumping engines, four water tube boilers, three small steam driven electric dynamos, a pumping and filter plant for the supply of the clean water required at the station, an overhead travelling crane in the engine room, and a workshop equipped with machine tools for repair work.

The main pumping engines are of the vertical inverted cylindrical fly wheel type, with a combination of four steam cylinders driving three pumps, the chief feature being the arrangement of the four cylinders, giving a modified form of quadruple expansion. The three lower pressure cylinders are arranged side by side as in an ordinary triple expansion engine; but the high pressure cylinder is placed tandem with and above the first intermediate cylinder. The two higher pressure cylinders are single acting, and are fitted with drop valves, while the lower pressure cylinders are double acting, and fitted with Corliss gear. This arrangement was devised in order to combine the advantage and simplicity of three pumps with the economy of quadruple expansion using high pressure steam, and also to make the engines more flexible and easily governed by introducing the steam initially into a small cylinder. The cylinder proportions are respectively 17″ × 27″ × 33″ × 49″ × 36″ stroke.

The cylinders are supported at the back by cast iron box shaped columns which carry the crosshead slides. At the front they are

supported by tapered steel pillars, which leave the front of the engine as open as possible.

The bed plates are of box shaped section, cast in three pieces and bolted together. They are held down to their foundations by bolts passing through the concrete arch.

The power is transmitted to the pumps by vertical pump rods, depending from and driven by the cross heads. There are two pump rods to each pump, arranged diagonally to allow the crank shaft to pass between them.

The crank shafts are of the usual built up type, and are supported on each side of each crank by main bearings. The ends beyond the fly wheels are carried by end bearings, supported on the concrete foundations.

The fly wheels, of which there are two to each engine, are 14 feet in diameter, and each weighs 12 tons. They are of sufficient weight to enable the engine to run steadily at 10 revolutions per minute.

The connecting rods are hung from the cross heads between the pump rods. No power is taken from the crank shaft beyond that to drive the valve gear and governor. Its office is merely to equalize the running of the engine.

The valve gear is driven by a lay shaft placed in front of the cylinders. Power is transmitted to this by a vertical shaft driven by skew gear supported on ball bearings. The exhaust valves are directly driven by eccentrics mounted on the lay shaft, and the steam valves, both drop valves and corliss valves, are driven by trip gear. The point of cut off in the H. P. cylinder is controlled directly by the governor. In the other cylinders, it is adjusted by hand.

The engines are fitted with platforms connecting the engines together and giving access to all parts. A stairway placed between each engine connects each platform with the floor. Receivers are placed between the intermediate pressure cylinder and low pressure cylinder. These act as re-heaters and are fitted with tubes through which live steam circulates.

Steam is delivered to the engines at a pressure of 200 lbs. per square inch superheated 150° F. Live steam is admitted to the cylinder jackets and re-heaters at a pressure of 80 lbs. per square inch through reducing valves.

Main Pumps.—The main pumps are placed beneath the engine and immediately above the sumps, from which they are separated only by the thickness of the arch forming their foundations.

There are three pumps to each engine joined together with common suction and delivery pipes. The pump bodies are of large capacity with regard to the velocity of water passing through them to avoid shock. They are as nearly as possible cylindrical in form, strengthened by ribs when the shape is modified to form the necessary openings.

The plungers are of cast iron 21 inches in diameter, working through stuffing boxes placed at the tips of the pumps. The stuffing boxes are arranged with a recess through which clean water flows at a higher pressure than the sewage in the pumps, thus preventing the entrance of grit and scoring of the plungers.

The suction and delivery valves are leather flaps backed with cast iron plates. They are carried on valve plates which are removable from the pump bodies. The valve seats are of cast iron inclined slightly from the vertical in order to ensure the valve remaining tight when closed.

The leather valve forms its own hinge, and is so arranged that it is bent through half the total angle of opening when closed. On opening, the leather is, therefore, straightened and then bent back the corresponding half angle. This arrangement puts less strain on the fibres and, in consequence, the life of the valve is prolonged.

The pump bodies have been designed to pass all the silt and debris contained in the sewage which passes the screens. For this purpose, the valves and waterways are arranged to offer as little obstruction as possible to solid matter. With this end in view, the delivery pipe at the outlet of the pumps is elongated in order

to allow a straight passage for the silt at the bottom, and the gases at the top.

An air vessel of large capacity is placed on both the suction and delivery ends of the pumps. These are charged with air by a small air compressor on each engine.

The suction pipe to each set of pumps is 24 inches diameter, and ends in a bell mouthed intake at the bottom of the sump.

The delivery pipes from each set of pumps are 21 inches in diameter and fitted with a reflex valve placed near the pumps. These delivery pipes join the Rising Main in the valve chamber outside the pumping station, where the main stop valves are grouped together and controlled by hand wheels placed above ground level.

The condensers are situated below the Engine House floor in a passage at the side of the pump chambers. The exhaust steam pipe descends through the Engine room floor, when it is carried to the condensers through an oil separator, which removes about 90 per cent. of the oil mechanically; the remaining oil is removed by a chemical tank in the boiler house.

Between the condenser and the oil separator is a tubular feed heater which imparts to the feed water the small remainder of heat in the steam.

The condensers are of the usual surface type with $\frac{3}{4}''$ tubes. They are designed to maintain a vacuum of 26 inches with cooling water at 80° F. The air and circulating pumps are driven from the main engine. They are placed in the pump chambers and are coupled to a crosshead carried on the main pump rods.

Each main engine is also provided with an air pump for charging the air vessels, a boiler feed pump, a lift pump for the condenser and an oil pump for lifting oil to a tank on top of the engine which feeds the lubricators.

The main pumps are each provided with a steam ejector for charging them.

The boilers are of the Babcock and Willcox type in four units corresponding to the four engines. Each has a heating surface of

983 square feet. The supply steam at 200 lbs. pressure superheated 150° F. They are stoked by hand, and the draught is that of a chimney 6 feet diameter and 150 feet high outside the boiler room.

The feed water is heated in an economiser of the usual tubular type placed in the main flue, a bye-pass flue being also arranged. The scrapers are driven by a small electric motor.

Coal is brought into the boiler house in small stoker trucks. These run on a narrow gauge railway placed at a convenient distance from the boilers for stoking directly from the trucks to the furnaces. The railway line in the boiler room is of a capacity to hold sufficient trucks for a day's supply of coal. As these are emptied, they are loaded with the ashes and pass over a weigh bridge placed near the door.

The weigh bridge punches the correct weight on a ticket so that, with the native labour employed, a correct record can be kept.

An auxiliary pump is placed in the boiler house of sufficient capacity to feed the boilers when the pumps on the main engine are not working.

The water supply from the Pumping Station is taken from an irrigation canal about 600 metres away. An artesian bore has been put down and provides an alternative supply, when the canal emptied for cleaning, to which it is liable for a period of about six weeks annually. The canal provides an abundant supply of good Nile water for all the purposes of the station. The water is raised by an electrically driven centrifugal pump situated on the canal bank, through a 10-inch diameter tank near the pumping station, where it is treated with alum in order to precipitate the silt, which at times of Nile flood is present in large quantities.

After settlement, the water is used for the condenser circulating service and for the general service of the station, such as flushing, etc. The water required for feeding the boilers and for the supply of the engineers' quarters is taken from this tank and filtered through a mechanical filter of the pressure type.

Storage tanks of eighty metres capacity are provided for filtered and unfiltered water respectively in the two towers of the main building.

A service pump capable of delivering 500 gallons per minute against a head of 200 feet is provided for the unfiltered water. This supplies the service mains and hydrants in the station, which are also connected to the reservoir in the water tower. This pump is of the compound steam Worthington type, and is placed in the pump room together with the pressure filters. The water to be filtered is pumped by a 4″ by 6″ triplex plunger pump driven by an electric motor.

The condensing water is stored in a sepaiate tank placed near the settling tank outside the Pumping Station. It is taken from this tank by a $\frac{1}{8}$ inch diameter suction pipe connected to the circulating pumps on the main engine and returned by a 12-inch pipe to the tank where it is cooled by passing through a rotary sprayer driven by an electric motor. These sprayers which are in duplicate are rotated rapidly, and the water is whirled out centrifugally in the form of a fine spray and so cooled by contact with the air.

The artesian bore water, being unsuitable for the boilers on account of the large amount of salt it contains, is only used for cooling purposes when the canal is dry, and the boiler feed is drawn from the settling tank which contains 1,100 cubic metres of canal water, isolated by valves from the cooling tank which then contains well water.

The electric current for driving the various motors and for lighting the building is generated at 220 volts by three compound condensing high speed steam dynamos of 60 kilowatts capacity each, running at 400 revolutions per minute supplied by Messrs. W. H. Allen & Co., Bedford. These are placed in the dynamo room and exhaust into an independent surface condensing plant placed at a lower level in the pump room; the circulating pump of the centrifugal type, and the air pumps of the Edward's type

are driven electrically and are connected to the mains serving the main pumping engines.

The station is lit by flame arc lamps suspended near the roof, augmented by a number of incandescent lamps carried by brackets on the walls. The wiring is on the distributing box system, the distribution boxes being of cast iron containing the various controlling switches and fuses mounted on a slate base.

Power is conveyed to the motors outside the pumping station by special conductors of bare copper carried on steel poles.

The engine room is provided with a travelling crane of 10 tons capacity worked by hand. This serves the main engine room, the dynamo room and the pump room. The workshop is provided with a three-ton travelling crane which also serves the smiths' shop. Both the standard and narrow gauge railway are brought in under both these cranes.

Venturi Meter.—Plate No. 63. The discharge from the main pumping station is measured by a Venturi meter placed on the rising main at a short distance beyond the point where the delivery pipes from the main pumps join the main.

The meter tube has a throat ratio of 1 to 12, and is capable of measuring all flows between 130 and 2,300 cubic metres per hour.

The piezometer tubes are arranged with dirt boxes fitted with perforated copper strainers in order to prevent the passage of solids likely to stop up the tubes. A clean water flushing pipe is also connected to keep these pipes clean.

The counter and recording instrument is placed in a small chamber immediately above the Venturi tube. The recorder is fitted with two drums which record respectively the variation in the flow and also the pressure in the Rising Main.

The counter is of the usual small dial pattern reading up to 7 figures. It is furnished with an electrical attachment which actuates a similar counter placed in the Engineer's Office.

Water Level Recorders.—A water level indicator, to show the level of the sewage in the sump, is fixed on the engine room wall

This consists of a dial 2′-6″ diameter with the water levels marked in feet. It is actuated electrically by a copper float in the sump. A recording instrument giving a weekly chart is also actuated by the same instrument. This is arranged in the Engineer's Office by the side of the Venturi Meter counter, so that the incoming sewage, as recorded by its level, and the output from the station as measured by the Venturi Meter, are conveniently placed together for inspection.

Rising Main :—The distance between the main pumping station and the sewage Disposal Works is 11 kilometres and the sewage is pumped this distance through a rising main 36 inches in diameter. At the main pumping station, each pump discharges through 21 inches diameter delivery pipes, all of which converge into a valve chamber which has been constructed large enough to contain valves and special junctions on the rising main, and to allow of these being always accessible. The rising main leaves the valve chamber at R. L. 13·00 and rises for a distance of 200 metres to a 33 inches diameter, Venturi meter on the rising main for recording the volume of sewage pumped.

The main, after leaving the Venturi Meter, is laid to follow the natural contour of the ground, with a minimum cover of 1·20 metres to protect the pipes from extreme variations of temperature, and further, at intervals not exceeding 1,000 metres, air valves, expanding joints and inspection manholes are provided.

The main is divided into 5 sections, each section being controlled by a 36 inches diameter sluice valve to allow of any section being isolated in the event of a burst occurring. The main has two distinct rising gradients and 2 reflex valves have been fitted at the low points.

The sluice valves are of the usual full-way pattern made of cast iron and all working parts are faced with gun metal, and are provided with 6 inches bye pass valves to allow of the pressure on both faces being equalised during the opening of the valves.

The reflux valves are fitted with cast iron hinge flaps, faced with gun metal capable of being easily withdrawn for inspection and repairs.

The main is composed of cast iron spigot and socket pipes, each 4 metres long and $1\frac{1}{4}$ inches thick jointed with lead. The pipes were cast at the Pont á Mousson Foundries in France, and as they were cast direct from the blast furnaces, without remelting, great care was taken in testing both the metal and the finished pipes.

Purification Works and Power Station at Gebel el Asfar :— The sewage discharges from the rising main into a concrete chamber 4·75 by 3·50 by 5·90 metres in depth. The floor is sloped to drain through a 0·61 metre cast iron bye pass connected directly to the main irrigation canal which feeds the farm. The bottom of the receiving chamber is at R. L. 29·50 while the level of the invert of the rising main is at R. L. 32·00. The rising main finishes with a bell mouth which deflects the flow of sewage in order to prevent erosion of the sidewalls.

The sewage leaves this chamber at R. L. 34·50 metres and passes over a weir and through a syphon into a channel 2 metres wide at R. L. 33·50 metres. From the channel, it is distributed into any of the 6 hydrolytic tanks through entrances controlled by penstocks.

These 6 hydrolytic tanks (Plate No. 64) are capable of dealing with 50,000 cubic metres of sewage, or the whole of the dry weather flow in 24 hours, and are constructed entirely of cement concrete, the arch and vertical central walls being reinforced.

Each tank contains two side sedimentation chambers, having submerged inlets controlled by penstocks. The sewage, after travelling the full length of the tank, passes out at the end over two weirs, the length of each being equal to 40% of the total weir length of the tank, so that a flow of 10% is supplied downwards and helps to carry any settled solids into the liquifying chamber. The liquifying chamber is V shaped, and the floor is divided into 6 sludge chambers each separated by a low dwarf wall, and provided

at the lowest point with a sludge draw off fitted with a plug controlled by long spindles. The sewage enters this chamber through the openings provided at spring level of the arch and emerges at the end over a weir, the discharge length of which is equal to 20 % of the total output of the tank.

When designing the filters, the author took into consideration the position of the purification works at Gebel el Asfar. The farm and the works are far away from any inhabited place, the nearest town, that of Khanka, being 5 kilometres in a westerly direction.

All the buildings for the staff at Gebel el Asfar are built to the north of the works, so that the prevailing wind, which is from the north, will blow away from the inhabitants any disagreeable smell that may arise. Taking everything into consideration, it seemed unnecessary, on a sewage farm almost entirely composed of sandy soil, to treat more than the strongest part of the sewage. It was, therefore, decided to filter only the effluent which is discharged from the liquefying chamber, passing the whole of the effluent from the sedimentation chamber directly on to the farm without any further treatment. So far, this has been a distinct success. A good effluent is obtained from the filters, and when the sedimentation tank effluent is mixed with it in the same carrier, the admixture forms a liquid practically free from matters in suspension, and which can be passed on to the farm without nuisance or fear of the land becoming clogged.

For the removal of sludge, 12″ cast iron pipes are laid with gradients of 1 in 120 and 1 in 200 under the floor of the Hydrolytic tanks and the storage tanks to the sludge pumps. The sludge is lifted by two centrifugal sludge pumps on to high sandy ground laid out as a drying bed. The pumps are contained in a chamber and are direct coupled to electric motors.

In the sedimentation chamber, a contact of 3 hours is allowed on 80% of the daily flow of sewage. The liquefying chamber which deals with the 20% allows a contact of 9 hours and the 6 sludge

chambers at the bottom are equal to 1 hour's capacity of the daily flow.

The total capacity of the tank works out to 6·2 hours of the daily flow.

The tank effluent is conducted to the filter beds through a 1·50 metre rectangular channel from which it flows into 4 feeding channels constructed of reinforced concrete, and the water supply to each feeding channel is controlled by rectangular penstocks.

The distributors, of which there are 8, were made by Messrs. Ham Baker & Co., London, and are composed of two main pipes or tubes, spanning the width of the filters and supported on end carriages running on rails laid on each side of the filter beds. These pipes are arranged side by side in such a way that a third pipe, slung between them, leaves a small space through which the sewage flows as nearly as possible in an unbroken film over the surface of the filter beds, leaving just sufficient clearance between the tubes and the surface of the filtering medium to prevent contact with the air. In this way, the sewage is spread in as even a manner as possible with a minimum of smell. The sewage is fed into each distributor by means of a syphon dipping into the feeding channel, the water in which, being at a higher level, flows through the syphon. Sliding valves or penstocks, which are automatically opened and closed by stops at each end of the bed, regulate the flow in such a way that alternate halves of the bed are watered when the distributor is travelling in each direction. This ensures even dosing with an even time limit between the doses.

The travellers are provided with an automatic gripping arrangement which alternately grips wire ropes travelling in opposite directions. The grip is reversed at each end of the beds by suitable stops, and is maintained until the next reversal by a lever composed of a balanced pipe containing water which acts as a moving weight.

The wire ropes are driven by electric motors, each provided with a worm and spur wheel reducing gear. The motors are arranged to give a speed variation of from 6 to 12 revolutions

per minute. The wire rope is passed over a series of grooved drums connected together by an endless chain, and is kept taut by means of a weight placed at the opposite end of the filter beds to the driving gear.

Each rope, which is $\frac{3}{8}$ inch diameter, drives two distributors. Two motors and driving gear are contained in each of the two motor houses, the endless wires being brought in over pulleys. The starting panel is provided with a variable shunt resistance, and automatic overload and low volt switches.

The filter beds (Plate No. 65) are rectangular and constructed of cement concrete floors, and brickwork superstructure. The floors are graded laterally to two side and one central channel laid under the tank effluent, which leads on to the storage and settling tanks.

The filter beds have a 2 metre depth of medium carried on false floor tiles. The bottom layer, immediately on the floor tiles, is composed of gravel graded from 3 inches to 4 inches diameter and hand laid for a depth of 0·22 metres. The body of the filter is composed of gravel graded from 3 inches to $1\frac{1}{2}$ inches and the top layer has a depth of 0·22 metres of $\frac{1}{2}$ inch to $\frac{3}{4}$ inch gravel. The filters are designed to treat 20% of the ultimate flow of 50,000 metres with a maximum rate of treatment of 885 litres (195 gallons) per cubic metre per day.

The storage tanks have a liquid capacity of 5,300 cubic metres and are intended for storage of the night flow. These tanks are constructed of cement concrete and the floors are graded to central channels which are provided with sludge draw offs. The water is admitted at the Northern end (fig. XVII) through penstock openings, and passes into the main distributing carriers through floating arm draw offs of 0·456 metre diameter. An overflow weir is constructed at R.L. 30·35 metres, and should the storage capacity not prove sufficient for the night flow, the effluent overflows on to the main irrigation canals of the Farm.

The power required to actuate the various machines and pumps

on the purification works and also on the Farm is generated in a power station (Plate No. 66) situated near the Purification Works, and as the various points at which power is required are scattered over a large area, the energy is developed electrically and conveyed by means of over head cables of bare copper wire carried on steel poles.

The power station is placed in the most convenient position with regard to the points to be supplied with power and occupies, as nearly as possible, the electrical centre of gravity of the system.

The plant consists of three crude oil engines driving dynamos of 45 kilowatt each, and one kilowatt dynamo driven by a small high speed pattern engine.

The crude oil engines are of the semi diesel pattern (built by Messrs. Ruston Proctor & Co.) Each engine is capable of developing 60 b.h.p. when consuming the ordinary crude oil supplied from the Egyptian oil wells.

The consumption of fuel being about 0·6 lbs. of crude oil per b.h.p. per hour when developing full load on the ordinary working conditions.

The engines are of the single cylinder pattern. They are fitted with extra heavy fly wheels, which give a very steady light with no appreciable flicker, and with governors which control the quantity of oil delivered to the cylinder at each explosion stroke. They are fitted with compressed air self starting gear, the air for which is delivered at a pressure of 200 lbs. per square inch by a small auxiliary air compressor of the Revel type.

The dynamos are of the ordinary compound wound type rated to give an output of 45 kilowatts. They are directly coupled to the crankshafts of the oil engines by means of flexible couplings.

The small 7 kilowatt set is principally for taking the lighting load and driving the workshop when the main engines are not required. All the four dynamos are arranged to work in parallel.

The building contains in the main engine room an overhead travelling crane capable of lifting 8 tons which serves both the

engine, and a small workshop which adjoins. The workshop is fitted with a few machine tools capable of dealing with any small repairs required.

The Chemical Aspect of Sewage Disposal at Gebel el Asfar:— On account of the very limited time during which sewage has been treated, and also owing to the fact that only a small proportion of the volume of sewage to be ultimately treated is as yet dealt with, it is impossible to state definitely what the strength of the crude sewage will finally be, but up to the present, it has varied from average to strong. The sewage is essentially domestic and will always remain so. It contains a comparatively large amount of undecomposed soap, which adds to the difficulties attendant on its disposal.

The last sample of crude sewage examined had the following composition :—

Parts per 100,000.						
Total Solids.				Nitrogen as		Oxygen Absorbed.
Suspended.		Dissolved.		Free and Saline Ammonia.	Albuminoid Ammonia.	
Organic.	Inorganic.	Organic.	Inorganic.			
34·0	33·2	36·0	65·6	6·00	1·05	23·7

And the last samples of tank effluent examined gave the following results :—

Major portion 80%.

Parts per 100,000.						
Total Solids.				Nitrogen as		Oxygen Absorbed.
Suspended.		Dissolved.		Free and Saline Ammonia.	Albuminoid Ammonia.	
Organic.	Inorganic.	Organic.	Inorganic.			
7·2	2·4	32·6	67·2	8·00	0·30	16·1

Percentage Purification :—

78·8	92·8	8·8	..	..	71·4	32·0

Minor portion 20%.

Parts per 100,000.						
Total Solids.				Nitrogen as		Oxygen Absorbed.
Suspended.		Dissolved.		Free and Saline Ammonia.	Albuminoid Ammonia.	
Organic.	Inorganic.	Organic.	Inorganic.			
Trace ..	4·4	35·2	65·2	6·00	0·35	15·6

Percentage Purification :—

100·0	86·7	2·2	0·7	..	66·6	34·2

The final effluent and the sludge are both applied to the land.

The last sample of filter effluent analysed gave the following results :—

Parts per 100,000.							
Total Solids.				Nitrogen as			Oxygen Absorbed.
Suspended.		Dissolved.		Free and Saline Ammonia.	Albuminoid Ammonia.	Nitrates present.	
Organic.	Inorganic.	Organic.	Inorganic.				
1·2	0·8	28·8	69·2	4·80	0·222	1·33	3·4

Total Percentage Purification on the Crude Sewage :—

96·5	97·5	20·0	..	20·0	79·0	..	64·5

Gebel el Asfar Farm :—When designing a scheme for the disposal of the sewage of Cairo, there was no doubt in the Author's mind that Egypt was an ideal country for sewage farming. The absence of rain makes the success of a sewage farm certain, and it was early decided that all the sewage of Cairo and its suburbs should be disposed of on land and used for cultivation purposes. A large number of sites on the desert adjoining Cairo were inspected, and finally a site to the north-east of the new Lunatic Asylum which was being built for the Public Health Department was suggested.

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This site, which is some 5 kilometres to the east of the town of Khanka and known as a Gebel el Asfar (The Yellow Hill), was carefully considered and a series of bores were taken all over the area intended for the Farm to discover whether, as so often happened in Egypt, there was any considerable amount of salt in the soil. The following analysis supplies a fair average specimen of the greater part of the surface soil of the area.

Average nature of samples.	Depth.	Total salts.	Common salt.
Reddish sand, loam and sand ..	1 m·50	0·09%	0·03%

The soil naturally is very sandy and varies from a sandy loam to almost a pure sand. The great need in the way of plant food of such a soil is nitrogen, and this need the sewage and the sludge will supply, and there is no doubt that excellent crops of fruit and of market garden produce can be grown. Like desert soils in Egypt, however, the soil at Gebel el Asfar contains salt, but this should readily all bewashed either into the subsoil, or to the lower lying areas.

The area has a further advantage inasmuch as the purification works are protected from heavy winds from the north or north-east by high sand dunes.

The site was levelled, and the land was found to have a fall of several metres from north to south in the whole length of three kilometres.

Allowing for all purposes, such as roads, villages, purification works, railways, etc., an area of 3,000 feddans was decided upon and taken over from the Government Lands Department, and boundary pillars fixed.

The Decauville railway of 60 centimetres gauge referred to in the earlier part of this paper was constructed along the route of the rising main, and this gave access to the Farm from the main pumping station at Kafr el Gamous.

Arrangements were also made with the Egyptian State Railways to construct a siding to the site of the Purification Works, from the main line. In addition, 9 kilometres of Decauville railway were laid along the main roads of the Farm for access to various plots.

Although the Farm sloped generally from north to south, there was a good deal of levelling to be done. By arrangement with the Prison Department, 600 convicts, chiefly men of life sentence or long terms, were removed from the Prison to a camp constructed for them on the Farm.

As far as possible, the levelling work was carried out by piece work, *i.e.*, each gang had to do 3 metres cube of excavation and filling per man per day, and when the whole gang had done an amount equal to that, they were allowed with their warders to return to the camp. This practice was followed during the whole of the time the convicts worked at Gebel el Asfar, and in a general way it was quite successful. By the end of the 5 years, some 360 feddans were completed and ready for cultivation.

Roads were laid out and houses were built for the staff in the very early stages of the scheme, and the drainage from them was purified at a small installation, and the effluent used for experimental purposes.

Potable water could not be obtained on the Farm, and it was necessary to sink bores at various points within the zone of the Ismailia Canal some 3 kilometres due west from the staff houses. Good water was at last found some 20 metres below ground, and it is pumped by oil engines to the reservoirs on the top of a high sand dune due east of the houses. From here it gravitates to the various points of supply. No filtering of the water is necessary, as the bore is in fine sand.

Before any crops were grown on the Farm, the different kinds of cereals, fruit and vegetables which grow well in Egypt were tried in the experimental garden. Though the area was small evidence was obtained to show that with treated sewage, an average

of 100% better results could be obtained generally than with Nile water.

In order to ascertain what crops would be the best to grow a small area of berseem (lucerne) lupins and beans was sown in November 1910. These did very well up to February 1911, but a severe sandstorm on the 10th ruined the whole of the crop; the sand covering them to an average depth of 0·40 metres.

After this experience, it was evident that one of the essentials to the success of any cultivation at Gebel el Asfar was the provision of shelters from the sandstorms, and attention was then given to the best methods of planting the tree belts to act as wind screens. It was finally decided to divide the Farm into plots varying from 8 to 10 feddans, sheltered on every side by a tree belt, the main belts running from east to west, about 200 metres apart, consisting of 6 rows of trees planted two metres apart and the belts running from south to north to be two rows of trees 2 metres apart.

Special attention was also given to the choosing of the trees most suitable for giving effective shelter, and as they would occupy good land, for yielding a revenue to Government in timber. The following were the trees planted and experimented with, *viz*:—Eucalyptus, Tamarix, Syssoo, Sunt, Casuarina, Cypress, Wattle and Grevillea, and it was found after two years' experience that the most suitable tree to answer both purposes was the Tamarix. Besides making a very effective shelter, the timber is used largely for making native boats and sakiehs. The wattle was found to be the next, making a very good shelter, but the timber is of very little value except as firewood.

Before any tree planting could be started, water had to be found, bores were sunk and engines and pumps erected on the sites. A plentiful supply of water was found anywhere on the Farm at R.L. 12·00 and bores were sunk as low as 70 metres from the surface.

The water was found to be brackish as is the case all over Egypt, outside the zone of the canals or the Nile. Some 40,000

trees now exists in the belts, and some of the Eucalyptus have grown nearly 30 feet in height in the 3 years, and they have all been irrigated with water from the bore holes.

After the levelling was completed, it became necessary to decide on the kind of sewage carriers for the irrigation of the Farm. Main carriers and submain carriers were designed to carry an amount equal to 50 cubic metres per feddan per day and their size calculated according to the area which they were intended to irrigate. These carriers were constructed of cement channels with sides of cement slabs laid dry. The cement and sand were mixed in proportion of 8 to 1, and the more intelligent of the convicts were used for the construction of them. Some 6 kilometres of carriers are now in use on the Farm. At their junction with smaller carriers penstocks of the very simplest form are provided to carry the sewage to the different area enclosed by the tree belts. In the centre of the present levelled area, a village has been constructed of hollow 8 to 1 cement blocks for the accommodation of the labour required. Some 48 houses have been built, 32 for married and 16 for single men, with a special house for the head man or "Nazir," and with separate houses for shops and general stores. This accommodation has been provided for a population of 300.

Water has been laid on from the main potable supply. Washing places have also been provided and separate latrines for men and women.

In April 1914, the first sewage was pumped from the end of the main collector at the main pumping station by a temporary pump to Gebel el Asfar through the rising main, and as the hydrolytic tanks were not at that time quite complete, it flowed on to the Farm in its crude state.

On November 1st, 1914, however, one of the large pumps at the pumping station was started, and since that date, pumping of sewage has been continuous. It has all been passed through the hydrolytic tanks, and 20% of the whole has gone through the filters.

At the beginning of 1914 some of the tree belts had grown sufficiently to protect and admit of fruit trees being grown, and by the end of January 1915, the following trees were planted, *viz.*, mandarines, oranges, limes, pomegranates, figs, date palms, vines, guavas, olives, apricots, quinces, prickley pears, lemons, adalia, mulberries. In all about 35,000 were planted.

The growth has been so successful that during 1914, small crops were obtained from the vines, oranges, figs and pomegranates, promising that in the future, as these trees come to maturity, large crops will be obtained. Cereals also promise exceedingly well: wheat, barley, lentils and even beans, which usually require rich soil, give promise of great profit under sewage cultivation.

The Author has every confidence in the future of Gebel el Asfar and, with careful supervision, the farm should be a source of great profit to the Egyptian Government, and yield a net return of from £E. 10 to £E. 15 per feddan annually.

The estimated total cost of the scheme when completed, amounts to £E.1,971,821. Up to March 31st, 1915, about £E.1,541,000 has been spent, leaving £E.430,820 to be expended on the completion of the 270 kilometres of sewer reticulation.

It is estimated that the upkeep of the scheme, exclusive of interest and amortisation of capital expenditure, will amount to £E. 32,440 per annum, or 1·6% of the capital cost.

The following information is appended for use in connection with the paper and also gives the meaning of local terms that have been used :—

Borne Fontaine ..	Stand pipe for supplying main water.
Chareh	Street or Road.
Ezbeh	Small village or large agricultural estate.
Fosse	Cesspool.
Gebel	Mountain or Hill.
Kafr	Large village.
Nazir	Head man of Ezbeh.
Tekeih	Alms Houses.

LOCAL MEASUREMENTS.

Pic ..	.. 2·461 feet or 0·75 metre.
Feddan ..	.. 1·038 acres.

METRIC MEASUREMENTS.

Lineal metre	.. 3·28 feet.
Millimetre ..	.. 0·003 of a foot.
Kilometre ..	.. 3280·89 feet or approximately 0·62 miles.
Square metre	.. 10·76 square feet or 1·19 square yards.
Hectare or 10,000 square metres—2·47 acres.	
Cubic metre	.. Approximately 220 gallons or 35 cubic feet.
Litre ..	.. 0·220 gallons or approximately 4½ litres—one gallon.

EGYPTIAN MONEY.

£E.—(Pound Egyptian)	= £10s. 6½d. Sterling.
Mills. (Milliemes)	= 1·1000 of an Egyptian pound.

Since the above account was written the overall efficiency of the Pneumatic System from steam cylinder to Ejector, with 20 Ejector Stations working, out of a total of 63, and after eighteen months' working, has been officially declared by the Egyptian Government to be 37·39 %.

The Author specified that an overall efficiency of 35 % must be obtained, and it is satisfactory to note that this has been exceeded.

In connection with the above trial it is also interesting that an additional allowance of 4·75 % was made in the rated capacity of the Ejectors, to make the volume of sewage raised by these Ejectors coincide with the volume registered by the Venturi Meter, which had been previously tested by chemical methods and found correct.

DRAINAGE OF ALEXANDRIA.

At the end of 1902, the Author, at the request of the Egyptian Government, was asked by the Municipality of Alexandria to give his opinion on a scheme for the sewerage of that City which had been recommended by the late Dr. J. Hobrecht, Chief Engineer to the City of Berlin, and designed by L. Dietrich Bey, Chief Engineer to the Municipality of Alexandria.

The population of Alexandria, taken at the Census in 1897, was returned at 319,760. Alexandria has an excellent and never failing water supply, supplied by the Alexandria Water Company from the upper reaches of the Mahmoudieh Canal, and filtered before delivery into the City mains.

In the year 1902, the Company supplied 25,500 metres or 5,610,000 gallons of water per diem, equivalent to 85 litres or 18·5 gallons per head of population.

The rainfall of Alexandria is slight, and is mostly confined to December and January, the average annual fall for the last thirty years (1869 to 1899) being only 224·8 millimetres or 8·47 inches.

The configuration of Alexandria approximates to that of Bombay, that is to say, a considerable part of it is low-lying, being nearly at mean sea level. The range of the tide is so little around Alexandria that it can safely be left out of consideration so far as the sewerage is concerned.

Some thirty years ago, the export merchants of the City founded an Association and voluntarily contributed to a tax for the paving of the streets of a part of the City known as Minetel-Bassel. Subsequently, they extended their operations to other parts of the City, and increased the scope of their work by constructing a series of drains for the removal of surface water, but these drains were never intended for sewage.

The City, so far as its sewerage was concerned, remained in this condition until the year 1885, when the Egyptian Government appointed a Commission to report *inter alia* on the sanitary condition of Alexandria. The Commission condemned the existing drains for the use of sewage, but nothing further was done. In 1895, Dr. J. Hobrecht, Chief Engineer to the City of Berlin, reported favourably on a scheme for the drainage of the City which had been proposed by L. Dietrich Bey, Chief Engineer to the Alexandria Municipality. This scheme was to dispose of all the sewage of the City by gravitation on a combined system and to discharge it in a crude state into the sea. It was proposed to construct a main

sewer or collector, of ovoid shape, alongside the quay wall built between Pharos and Silsileh. This sewer was to receive sewage from eight smaller sewers and was to discharge into the sea at both its ends. This main and the smaller sewers were to be fed by a series of pipe sewers, serving the different districts of the City. Many of the gradients proposed were too flat to ensure satisfactory velocities.

There were many objections to such a scheme. The shape of the ovoid sewer was obsolete, and, where the rainfall of a City is so small, that shape of sewer is not to be commended. The effect of discharging all the sewage of the City into a collector, the outfalls of which are only partially submerged, is bound to be disastrous. Moreover, the discharge of a large quantity of crude sewage into the sea close to a City is a most objectionable proceeding and is certain to be fraught with serious results. The Author, on these grounds, reported against the scheme.

The configuration of Alexandria does not lend itself to a sewerage scheme entirely by gravitation.

Its close proximity to the sea provides a natural and economical outfall for sewage, but the latter must be biologically treated before being discharged.

Since the above was written a complete scheme for Alexandria has been designed by Mr. Lloyd Davies, M. Inst. C.E., who was appointed as the Municipal Engineer for the town of Alexandria in 1907.

Before giving a brief description of his scheme, it will be well to further touch on the scheme designed by Dietrich Bey in 1892, which the Author reported on in 1902. Dietrich Bey's scheme dealt with an area lying to the North of the line joining Pont Zulficar on the Mahmoudieh Canal, and, briefly, it consisted of a collector general encircling the Bay of Port Est, with outfalls emptying the sewage into the sea at Ports Kait Bey and Silsileh. To protect this collector, it was considered necessary to build a sea wall around Port Est.

Radiating from the collector general were 8 main tributary collectors, of which that of the Midan was to be laid along a new street cut through the isthmus of the Town. The Ibrahimieh collector passed along the present Rue des Soeurs, and penetrated to the Mahmoudieh Canal, and was connected with Gabbary by means of an inverted syphon.

The Collector Est was to be laid along the bed of the old Farkha Canal extending through the Rue Monasce to Moharrem Bey.

These main tributary collectors were large sewers attaining a considerable depth on the water-shed of the town, which they pierced so as to minimise the use of pumps.

Though the number of collectors was large, they did not drain the low-lying part of the land skirting the Mahmoudieh Canal nor take into consideration any land east of the Farkha Canal.

One of the remarkable features of the scheme was the construction of a reservoir on the Minet el Charagua, which, being filled by means of pumps from the Mahmoudieh Canal was to supply water for flushing the chief collectors proposed. This scheme was placed before the late Dr. J. Hobrecht, Chief Engineer of the City of Berlin, in 1893, and in his report he strongly supported the construction of the quay wall around Port Est and supported the collector general, but he objected to the design of the collector general in two branches, and strongly advised the conveyance of the whole of the sewage to the outfall at Silsileh by means of flat gradients.

In 1902, as before stated, the Author reported on the scheme, and objected to several points, notably the collector general.

Matters stood as above when Mr. Lloyd Davies was appointed Municipal Engineer. His first important work was to take up energetically the question of a sewage scheme for the whole City.

Plate No. 67 is a plan of Alexandria showing the principal collectors and the outfall proposed. The situation of the City, as shown on the plan, is on a narrow strip of land between Lake

Mariout and the Mediterranean, and at once suggests the disposal of the sewage by discharge into the sea.

The great length and narrow width and comparative flatness of the city area obliged Mr. Lloyd Davies to exclude Mex and Ramleh, beyond the Sporting Club, from his scheme.

Investigations showed that there were 65 kilometres of old sewers and, so far as is possible, these have found a place in the proposed scheme.

That scheme comprises the whole of the City lying between Gabbary on the West and the Sporting Club on the East. The present population within that area has been taken as 300,000, while the future maximum population is estimated at 349,000, but the scheme is capable of dealing with 450,000, should the density of the population become greater than is indicated at the present time.

The sewage flow of the city has been estimated from actual gaugings taken over a long period in existing sewers, and in defined areas, and the average figures selected is 160 litres (35 gallons) per head per day.

The town of Alexandria is built in its main part on very treacherous ground, and in the lower parts the sub-soil water is very near the surface. Deep sewers, therefore, have been avoided.

Mr. Lloyd Davies has rightly gone on the principle that where self-cleansing gradients can be obtained, simple gravitation must be adopted and economised to the best advantage, but where they are not available, mechanical elevation must be introduced.

The town naturally divides itself into three main areas.

An imaginary line drawn from Kom el Chougafa to the Hadara Hills separates a wide tract which slopes in a southerly direction towards Lake Mariout from that falling in a northerly direction towards the Mediterranean.

On the northern side of this line, extending as far as the Midan quarter, an important district is situated possessing good natural

slopes, but the Midan quarter itself forms a district lying so low that no natural facilities for drainage exist.

The main collectors will convey the storm water from the northern slope directly to the general collector, which is capable of conveying from 4 to 6 times the normal dry weather flow by gravitation to the present outfalls. The excess only, which in times of heavy rain can amount to 50 times the dry weather flow, will be diverted by means of over flowchambers directly into Port Est, and in this manner any undue pollution and nuisance in the Bay from the first flush during rainfalls will be avoided.

On the low-lying areas of the southern slope, where mechanical elevation for the sewage flow is essential, it is necessary to reduce the amount of water to be elevated to a minimum, and therefore the existing separate system for rainwater drainage must be extended and so designed as to convey its rainfall to its outfall in the Lake Mariout.

The only rainfall that is to be mechanically elevated under the scheme is a portion of that falling on the Midan quarter, for which, owing to its very low level, no natural outlet can be obtained by gravitation.

The situation of the new main collectors is marked by red lines, the existing collectors being shown in black.

Beginning at the point of outlet, the outfall between Forts Aida and Kaied Bey, it will be seen that the whole of the sewage of the town is collected at this point and discharged through the outfall to point A., 800 metres out to sea, the pumping machinery and screening arrangements being situated at point B.

In times of rainfall, the pumping station will be automatically disconnected by the rise of the sewage in the collector, and the full flow will discharge at the present outlets on the eastern side of the Fort Kait Bey and Fort Silsileh. Small breakwaters will have to be constructed at both these places to prevent the present serious interference of the flow by wave action.

Commencing with area marked I on the plan (the Ras el Tin and Midan quarters), it will be noticed that the whole of the area gravitates to point B. and the existing collector general, with the exception of a small hatched portion in the centre which requires mechanical elevation. This will be accomplished by two sub-stations at points C. and D. the sewage flowing into the collector general and the rainwater into the sea at point E. The Babel Akhdar collector will join the collector general at point F., an overflow weir for storm water into the sea being included at this point.

The next large area, No. 2, called the Anastassi area, is drained into the collector general at point G. by the main Anastassi collector, and passes by an overflow weir into the Bay. The sewage from the hatched portion in the extreme south will be collected at point H. and elevated into the main collector at point I, the rainwater being allowed to gravitate by means of the separate system into the canal.

Area No. 3 is drained into the collector general by the El Kaied Gohar collector at point J., where the storm water passes to the Bay by an overflow weir opposite the Rue Anastassi at point F.

Area No. 4 is served by the Saleh el Dine collector which drains the whole of the sewage into the Port Est collector at point K, where an overflow weir is provided to deliver the rainwater into the collector general by which it flows to the existing outfall at Silsileh. The hatched portion of this area in the south will be elevated at points L. and M. into the collector at point N., the rainwater being collected and gravitated into Lake Mariout at point O.

Area No. 5 will be drained by the Moharrem Bey collector, which will discharge its water into the existing Est collector at point P. at the Route d'Aboukir, from thence it will continue to the 30 metre road at point Q. and continue in a westerly direction along the 20 metre road on the New Quays to point B., again discharging its rainwater at point K. en route.

The sewage from the southern portion of this area will be collected at points R. and S. and lifted into the main collector at point T., the surface water will be conveyed under the Canal and discharged into Lake Mariout at point U.

The southern area No. 7 east of the Canal Farkha, which is an extension of No. 5, is not included in the present estimates, but provision has been allowed for it being taken into the present scheme when it becomes developed.

The remaining area No. 6 extends from the Rue de la Colonne Khartoum to the Sporting Club, and comprises the districts of Ibrahimieh and Camp de Caesar. This area will be served by the Ibrahimieh collector extending from point Y. to the Moharrem Bey collector at point Q.

The hatched portion to be elevated will be collected at point Y., and at this point also the sewage from Ramleh will enter in the future.

It will be seen that the whole of the existing collector general is utilised under the scheme, it conveys sewage and storm water in a westerly direction from point J. to point B. and rainwater from point B, to the existing outlet at Fort Kaied Bey at point X.

The rest of the collector from point K. to Silsileh point V. will be utilised for the discharge of rainwater. The existing Est collector from point P. to point Z. will act as an overflow for the Moharrem Bey Collector, and for the conveyance of the washings from the Waterworks as heretofore.

A reference table is marked on the plan, Plate No. 78, on which is shown the number of the district, its area, present and future population.

The total length of the new main collectors amounts to 38 kilometres, and that of the branch sewers to 183 kilometres.

34 kilometres of existing sewers have been employed, whilst 31 kilometres have to be re-constructed.

For mechanical elevation, where necessary, of the sewage, Mr. Lloyd Davies has recommended the adoption of electricity

and says that, from whatever source the energy is derived, either from destructor works, a control power station, the Gas or Tramway Companies, is immaterial to the scheme. He says the total working expenses per year will be very low in comparison with that of cities of similar size and flatness.

The estimate for the complete scheme, based on the current prices at Alexandria, amounts to £E.308,000, of which £E.165,000 will be devoted to main collectors and £E.143,000 to branch sewers.

The annual working expenses in connection with the pumping plant it is estimated will not exceed £E.2,075 per annum, which with a sum of £E.1,325 for amortizement, gives an annual total of £E. 3,400.

A start has been made with the above scheme, but only a small portion has been carried out, and work for the moment is closed down owing to the War.

Unfortunately, Mr. Lloyd Davies has not remained to see the completion of his scheme, having taken up an appointment as Chief Engineer to Cape Town.

There is an area outside the Municipal drainage for Alexandria, and belonging to the Egyptian Government, known as the Ports and Lights and Customs Administration. This area, which is approximately 28 hectares, comprises the whole of the buildings in connection with the Docks and the Customs. All the buildings within the area at present drain either directly into the docks or into percolating pits. Both systems are bad, and especially the second, because of the high level of the subsoil-water and the nature of the subsoil, consisting, as it does for the most part, of fine sand, easily clogged with matter from the sewage. Two old municipal sewers have outfalls into the Docks. These outfalls discharge about 450 cub. metres of sewage respectively per 24 hours, and sewage of a very strong nature, containing a quantity of floating matter which putrifies and causes great nuisance, more especially in hot weather. Smells from these outfalls have been the cause of serious complaints. When the Municipal scheme is complete

the discharge of sewage from these outfalls will cease, but that cannot be for several years.

The Author has designed a small scheme for this area to connect with the Municipal scheme, but for the present it will connect with old sewers which now discharge at Kaeid Bay. The area is divided into two districts, and in each district is placed a small pumping station, where it is proposed to instal duplicate four inch Stereophagus pumps. The Author has erected two similar pumps in Cairo for dealing with crude domestic sewage without screening. These pumps have been working for more than a year successfully, and as the sewage received from the Ports and Lights and Customs Administration will be entirely domestic, there seems no reason why they should not be successful in this position. The motive power would be electricity, as it is possible to obtain it at a moderate rate from the Electric Lighting or the Tramway Companies in Alexandria. The current will be automatically controlled to suit the varying quantities of sewage. Station No. 1 will discharge through a 5 inch C.I. Sealed Sewage Main into an existing sewer in Sharia Sidi Abou Warda. Station No. 2 will discharge through a 6 inch Sealed Sewage Main into an existing sewer in Sharia Bab el Akhdar.

DRAINAGE OF PORT SAID.

THE town of Port Said is situated at the North end of the Suez Canal, and is built on a narrow and flat strip of land between the Mediterranean Sea and Lake Menzalah.

The town came into existence in 1869 on the opening of the Suez Canal, and as the Canal grew in importance so has the town increased.

In 1869 its area was about 135 hectares (335 acres) and its population very small; but in 1907, when the Egyptian Government took a census, its population was recorded at 48,255, of which 35,915 were Natives. Since then it has rapidly increased, and its population in 1915 is 57,000, and its area, due to the receding

of the sea and the filling up of the lake behind the town with the dredgings from the Canal, is now 433 hectares (1,072 acres) of which about 246 hectares (610 acres) can be considered as being built over.

The average level of the land above the sea level is only 6ft. and the level of the subsoil water varies from 2′-0″ to about 4′-6″ below ground level.

The question of the drainage of Port Said was first considered in the year 1884, in which year Messrs. Hughes and Lancaster sent out a model ejector, which was exhibited in the Ports and Lighthouse Offices. Nothing came of this, however, and the matter was dropped until the Spring of 1906, when the then Director General of Public Health took the matter up and asked Messrs. Hughes and Lancaster to prepare a scheme and estimate for the drainage of the whole town, and this they submitted in October of the same year.

Their proposal however was not proceeded with, and the matter remained in abeyance till February 1909, when the Egyptian Government instructed the Author to open an Office at Port Said and to prepare a scheme, and this was done on the "Separate System."

In November 1909, a petition, signed by the principal inhabitants, was submitted to the Minister of Public Works and the Financial Adviser to the Egyptian Government by a deputation representing the Egyptian, British, French, Italian and Greek Communities, who were viewing the delay in the carrying out of drainage with much apprehension.

The project, nevertheless, lay dormant again till 1911, when a Municipality was formed in Port Said, and it was understood that the drainage scheme was the one of the first matters to be dealt with.

This the Municipality did, and the scheme was modified and altered to a combined system, because the Suez Canal Company objected to the off-flow of any surface water into the Canal or basins.

The plans and specifications were finally completed and approved in the Autumn of 1912, and tenders advertised for at the beginning of December in that year, and finally approved and sanctioned in March of 1913.

Before the advent of the drainage, for the most part, the houses were drained into cesspools, the *fosse etanche* and *fosse a fond perdu* being used sometimes separately and sometimes jointly.

A few of the houses on the Canal front discharged the overflow from their fosses direct into the Canal, while the Eastern Exchange Hotel has a flat cast iron sewer discharging under pressure, direct into the sea.

In the native quarter, the drainage was primitive, in fact as primitive as possible. It consisted of two barrels sunk level with the floor in opposite corners of the room, one for washing in and one for defecating purposes. They were emptied when necessary by being baled out, the sewage from the barrels being usually disposed of in the open street.

As any number between four and ten men, employed on the coaling of the ships on the harbour; lived in these rooms, and used the barrels daily, their state of cleanliness can be better imagined than described. When the ground was only sparsely built over the disposal of the sewage by means of these fosses did not constitute a serious nuisance. The subsoil water was then very much lower than now, and the percolation into the subsoil was effective. But as the town grew and became more densely built over, with an ever increasing number of these fosses, the consequent fouling of the subsoil became much greater, and with the continued rising of the level of the subsoil water, the percolation became slower and slower, until, in the densest parts of the town, percolation may be said to have almost ceased. In other parts the cesspools overflowed into the basements of the houses and great and serious nuisances occurred. Then it was that the inhabitants began to consider the necessity of a drainage scheme. The method of disposal in the better class houses, that by the

Sewage Transport Companies, became very expensive, and was a serious tax.

These Companies employed portable steam pumps to empty the fosses. The contents of the cesspools were pumped into closed tank-carts and carted to and emptied at a depot some 4½ kilometres from the town.

These Companies charged the proprietor P.T. 11.5, (2*s.* 4*d.*) for each cartful containing one metre cube removed from the cesspool, and the total cost to the inhabitants of the town for this work averaged £ 5,000 per year.

Owing to the extreme flatness of the ground a drainage scheme on the gravitation system was out of the question, and some system of pumping had to be adopted.

It was decided to use the pneumatic system with ejectors, such as had been adopted for Cairo.

The town was divided into ten areas, each provided with ejector stations in central positions. These areas drain all the present built over area, and provision is made for four more areas to be included as the town extends, making fourteen areas in all.

The sizes of the ejectors vary from 50 gallons to 500 gallons depending on the area drained, the density of population, and the class of houses and persons in each area, whether European or native, and whether it receives the sewage from other areas, besides its own, to be repumped.

The average maximum daily total water supply (from the Fresh Water Canal which is a branch of the Ismailia Canal the head of which is at Cairo) to the town amounts to about 820,000 gallons of which 173,000 gallons are supplied to ships and 35,000 gallons used for street watering, leaving a total of 612,000 gallons for the town itself.

Taking the present population to be 57,000, this gives a daily flow per head of about 10·34 gallons. But it has been estimated that the native population only used about 5.72 gallons per head per day, and the Europeans of all classes about 26·4 gallons per

head per day, but the scheme is designed for a prospective population of 75,000.

Assuming that half of the total daily flow takes place in eight hours, the maximum total flow per min. equals 637·5 gallons or 102·16 cubic feet.

As stated before, the Suez Canal Company would not allow the surface water to be discharged into the Canal or basins, and therefore it was necessary to design the scheme on the combined system and allow for the surface water flowing to the ejectors and being pumped through the rising main to the sewage outfall.

The average yearly rainfall at Port Said is $3\frac{1}{4}$ inches, and this fall only occurs between the months October to April; from May to September inclusive there is practically no rain. In 1911, when the total rainfall for the year was 4·56 inches, rain fell on 25 separate days, making an average for each fall in that year of 0·182 of an inch. The greatest single fall in that year was one of 0·21 of an inch. The heaviest fall recorded was in March 1912, when 2·16 inches fell in less than twelve hours.

In the scheme, provision has been made for dealing with a maximum fall of 1 inch in 24 hours, assuming that $\frac{1}{3}$ of this rainfall reaches the sewers.

Preliminary Details:—The drainage area of the town, as previously stated, was divided into 10 ejector areas, of an average area of 25 hectares, each area being entirely independent of the others.

Work was begun on Ejector Area No. III, one of the largest areas, and offering a large tract of ground at that time entirely unbuilt over, but which was provided for building in the near future. This tract was selected for experimental reasons, it being advisable to gain some further knowledge of the quality of the subsoil, and of the amount of water to be expected, before proceeding with the work in crowded and narrow streets.

Accordingly a section of average depth was opened up and carried out during the first two months.

A sump, a few metres away from the lowest manhole, was opened, and a grip cut to it from the trench to lead off the water; the original scheme being to work every area with sumps placed roughly 150 metres apart, to avoid pumping through completed work.

This however was found to be very expensive, as in order to keep a sufficient amount of work in hand, two or even three sumps were obliged to be kept working at the same time.

These sumps were, therefore, in later areas superseded by one central sump at the ejector manhole, either adjoining the manhole and part of it, or a short distance away from it, with a grip connection, according to circumstances.

Subsoil.—The subsoil generally over the town was found to be rather fine sand with layers of small shells at varying depths from 1 to 4 metres.

In that part of the town that had been formed by the receding of the sea, the sand was very fine indeed, and abounded in shells and was of the same class throughout.

Towards the centre of the town as it now is, on the old foreshore (Quai Eugenie) a thick stratum of black clay was found, stiff enough to prevent water making at all rapidly. This stratum was met with at a depth of between $2\frac{1}{2}$ and $3\frac{1}{2}$ metres, and varied in thickness between 20 and 40 c/ms.

The subsoil in parts of the native quarter was for the first metre and a half, very bad, being composed of refuse and rubbish of all kinds strongly impregnated with sewage, the overflow from the fosses.

A few old fosses and pipes were met with, and occasionally the soil right down the maximum depth would be black with sewage. Otherwise the subsoil was fairly fine sand.

Pumping. The amount of water met with was, on the whole,

less than was expected. It had been anticipated that the height of the subsoil water, and the porosity of the sand, would lead to a large quantity of water entering the trenches in spite of close timbering below water-level in every case.

A large variation in the rate of percolation was found and near the sea the trenches made a considerable amount of water, but in the centre of the town where the sand was coarser and often sewage laden, comparatively little water entered the trenches and in some cases, if special care was taken with the timbering, the trenches could be worked very nearly dry.

This was also due to the fact that the pump, after a few weeks constant working lowered the subsoil water-level very considerably. In area No. III close to a pump it was found possible to work in dry sand to a depth of 3 metres.

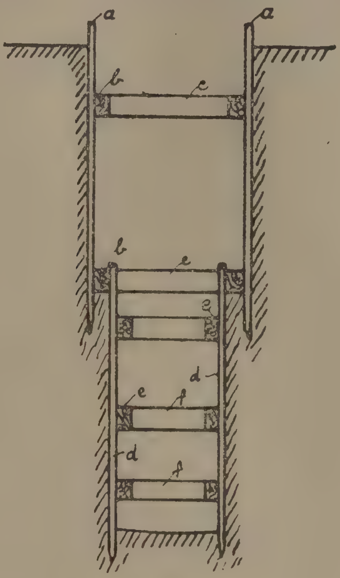
As a rule, a 4″ Centrifugal pump, run off an 8 H. P. portable engine, kept down the water, but on the commencement of some of the areas a 5″ and even a 6″ Centrifugal pump was found necessary. These pumps, after a few weeks however, had the work very well in hand.

It was found advisable to pump day and night whilst any work below subsoil water-level was being carried on, as if the pump stopped at night, the pumping dry of the trenches the next morning usually brought a large quantity of sand underneath the runners from the sides. Even with continuous pumping this was of frequent occurrence where the fine sand was encountered.

Owing to pumping through completed work much trouble was experienced in the silting up of the pipes, necessitating constant clearing.

Timbering.—Owing to the nature of the subsoil and the height of the subsoil water-level practically all the timbering was close sheeting ; only in the upper sections above subsoil water, *i.e.*, section from 1·0 metre to 1·50 metres deep was it found possible to use open timbering.

The sketch (Fig. 49) shows the form employed, and this was used throughout the work, varying the lengths of runners as required.



a.a. 2·0 m. poling boards 5 c-m.
b. 9″ × 3″ walings.
c. 6″ × 3″ struts.
d. 3·0 m. runners. 5 and 6 c-m.
e. 9″ × 4″ walings.
f. 6″ × 3″ or 9″ × 3″ struts.

A small amount of steel interlocking sheeting was used on a few sections, but it did not prove a success owing to the difficulty of handling it and the time it took to withdraw. No timber was ever in the ground long enough to make it worth while replacing it by steel sheeting.

The stoneware pipes used were, with the exception of the 6″ pipes draining very narrow streets in the native quarter, 9″ and 7″ with ruling gradient of 1 in 135 for 9″ and 1 in 100 for 7″.

These gradients give a velocity of $3\frac{1}{2}$ per second when flowing half full. Where these gradients were flattened ample flushing was provided. Generally a true invert pipe was used, but in cases where the water-level in the trenches could not be sufficiently reduced, *i.e.*, close to the lowest point of the area, a patent pipe, the "Keeptite", was substituted.

All pipes below subsoil water-level are laid on a concrete bed 6″ thick, and haunched up to half the pipe.

In the native quarter 6″ true invert pipes were laid in narrow streets where necessary, and given an average gradient of 1 in 50.

All house branches are 5″ and laid to the building line and an inspection Chamber built outside the house from whence the house connections are made at the owner's expense.

Ample provision was allowed for future buildings, both in the European and native quarters.

The manholes of one type similar to Plate Nos. 3 and 4 were used throughout the work with a few modifications. The half brick wall outside the manhole up to subsoil water-level, and enclosing a damp course of cement grout, was found to be very effective.

The ventilation of the sewers is effected by using the ventilated soil pipes of each building, as the house drains will not be disconnected from the sewers by traps. The lower end of the sewer will also be provided with a ventilating shaft connected to the inlet manhole and also to the air exhaust of the sewage ejectors. An underground air filter is being provided on each of these exhaust air pipes. The heads of all main sewers are also provided with ventilators.

Plate No. 68 shows the position of the various ejector stations with the accompanying sealed sewage mains and compressed air supply pipes. It will be noted that, besides the sewage from its own area, ejector station No. 8 receives the sewage from areas Nos. 1, 2, 3, 5 and 6, and in the same way ejector station No. 9 deals with that from areas Nos. 4 and 7 as well as from the proposed future Sections Nos. 12, 13, and 14. These two stations 8 and 9 repump the sewage to the sewage farm situated at the extreme west of the town. The repumping of the sewage at these two stations was necessary in order to avoid the excessive friction head there would have been in the sealed sewage mains, had the sewage been pumped directly from ejector stations at the east of the town to the disposal works, for the flow being small necessitated small diameter rising mains to give a self-cleansing velocity; the

length of the mains to the disposal works is about $3\frac{1}{4}$ miles.

The smallest diameter of sealed sewage main is 6 inches and the greatest is 16 inches.

The compressed air is supplied from a power station erected on a site to the south of the town opposite the railway station, and the main air pipe of 10 inches diameter is laid running north and branches are taken from it to the east and west which form a complete ring, so that in case of breakage at any part in the air main, the compressed air to any ejector station can be supplied from the other direction.

The ejectors and tubbings were supplied and erected by Messrs. Hughes and Lancaster, and are so well known that any description is unnecessary.

Power Station Machinery :—In deciding upon the plant for compressing the air for this scheme, the following considerations had to be taken into account :—

1. The great difference between the minimum and the maximum power required. The power required was estimated at about 10 B.H.P., and 320 B.H.P. respectively.
2. The great difference between the minimum and maximum dry weather flow. The power required was estimated at 10 B.H.P. and 45 B.H.P. respectively.
3. Heavy rainfall only occurs on a few days in the year.
4. The plant must be such that the full power should be available at short notice.

The following power plants were considered :—

1. Steam. 2. Producer gas. 3. Crude Oil.

Steam has the advantage of great flexibility, but the high cost of the installation and the higher manning cost and standing charges in view of the unsatisfactory load factor and the time taken to get up steam in an emergency were against its adoption.

The cost of fuel for a crude oil engine plant, and for a producer

Gas plant, would be about the same in Egypt, but the cost of installing and manning a Producer Gas plant would be greater than that of a crude oil engine plant. Crude oil engines were, therefore, decided upon for driving the Air Compressors.

The next question to be decided was the division of the units. It was impossible to divide the plant into a number of sets of equal power unless a great number were installed, otherwise the engines would have to run on very light loads for the greater part of the year. It was, therefore, decided to put in small and large sets. Many different arrangements with a combination of small and large sets were considered. It was decided to limit the output of the large sets to 600 c. ft. of free air per minute, compressed to 38 lbs. per square inch, so that they would not be too unwieldy and difficult to start, and so that a large portion of the plant would not be put out of action in case of the breakdown of one set.

The following arrangement was finally decided upon :—

One set to compress 300 c. ft. per min. to 20 lbs. per square in. B.H.P. at compression shaft 28.

Four sets to compress 600 c. ft. per min. to 38 lbs. per square n. B.H.P. at compression shaft 72.

The engines are Bates horizontal crude oil engines, each directly connected to a Reavell quadruple single stage air compressor.

The compressors are arranged so that any of the cylinders can be put out of action by passing the air from the delivery side of the compressor to the inlet side compressing the air. The compressors are arranged to be automatically put out of action in this way when the pressure in the receiver rises above 20 lbs. per square inch in dry weather and 38 lbs. in wet weather. The small set can be made to compress 175 c. ft. of free air per min. to 38 or 40 lbs. by cutting out two of the cylinders in this way, so that in wet weather there would be 2,400 × 175 = 2,575 c. ft. of free air compressed to 38 lbs. per square inch or about 100 c. ft. more than is actually required.

In dry weather the small compressor will be run at night and one of the large compressors during the day on about half-load, which is quite economical in the Bates Engine, the guaranteed fuel consumption of half load being 0·54 lbs. crude oil per B.H.P. per hour. In this way the small compressor will not be overworked, and the large compressors will always be kept in running order.

The engines are of the semi Diesel type, and are arranged for starting with compressed air. A belt driven Revell Quadruplex Compressor capable of compressing 15 c. ft. free air per minute, to 250 lbs. per square inch, delivers the compressed air for starting the engines to their high pressure receivers, which are connected to the starting valves of the engines. This compressor is placed in the workshop, and run from the workshop shafting.

Compressed oil vapour lamps are provided for heating the combustion chamber, when starting up only, the engines being capable of running on all loads without exterior heating after they have once been started.

Oil is injected into the combustion chamber by means of a pump. The oil supply is automatically regulated by the governor, so that there will be one explosion at every power stroke. The speed of the engine can be varied 5% above or below the normal by means of a hand regulator fixed to the governor. Forced lubrication is provided throughout the engines.

Two oil storage reservoirs, each of 15 hours capacity, are provided outside the compressor station. These are of mild steel, and are provided with oil indicators. The oil is pumped from the reservoirs to the engine supply tanks by means of Wilcox semi-rotary pumps fixed inside the engine house.

The air intakes to the engines and compressors are kept separate so that there will be no danger of back-firing from the oil engines into the air duct to the compressors.

The air intake chamber for the compressors is of brickwork, with a reinforced concrete rook. Wire gauze boxes are fitted

inside the openings in the brickwork. It is intended that during very dusty weather these should be filled with cotton wool. If lightly put in this will not cause wire drawing, as the free air required in dry weather will not exceed 640 c. ft. per minute, whereas the openings are sufficient for 2,600 c. ft.

The compressed air passes through two air receivers in series to a Kent's Venturi Air Meter. This instrument records the total output of compressed air, the rate of flow and the pressure and temperature of the air.

The cooling water for the air and oil engine cylinders is supplied from tanks placed on the roof of the cooler house. After passing through the cylinder jackets the water flows into the drain pipes through open channels so that it may be seen that the jacket water is circulating properly.

The outlet water from the jackets drains back to a pair of Heeman mechanical coolers. After passing through the coolers it drains into sumps, from which it is raised up to the tanks on the roof of the cooler house by means of centrifugal pumps. The water may also drain back direct to the sumps from the engines without passing through the coolers. In the case of small engine the cooling water may also be pumped direct to the tanks from a small sump placed by the engine. The pump for this purpose is worked off the engine crank shaft.

The shafting from which the coolers and pumps in the cooler house are operated may be driven by an electric motor placed in the cooler house or by connecting up to the workshop shafting.

At one end of the compressor station a workshop is provided. This contains a lathe, a slotting machine, a drilling machine, a pipe screwing machine, an emery grinding machine, a fitter's bench and a supply of all necessary hand tools. The workshop shafting is driven by an oil engine. This engine is of sufficient power to drive the cooling plant machinery and the high pressure air compressor at the same time, this being the maximum power for which it is necessary to provide.

An overhead travelling crane, which can be operated from the floor and which is capable of lifting 10 tons is provided for the engine house and machine shop. The engine house is separated from the machine shop by a partition wall which is carried up to a height of four metres. The crane can pass over this wall. A part of the shafting between the cooler house and machine shop can be removed to allow the crane to pass. If it is necessary for the crane to pass over the wall when the cooling machinery is running, the shafting in the cooler house will be driven by the electric motor provided.

Repairs :—It is intended to carry out repairs for all machinery, carts, wagons, road, rollers, etc., belonging to the Municipality, and in addition to the workshop mentioned above a blacksmith's shop and a carpenter's shop will be provided in separate sheds in the compressor station yard.

The Sewage Disposal Works and Farm are situated at the extreme west of the town and the sewage is delivered thereto by means of a 16 inch cast iron rising main. This main is provided with a Kent's Venturi Meter, with a 5·33 inch throat which is capable of registering all flows between 9,600 and 60,000 gallons per hour at a friction head of 9 inches. It is provided with an electrical alarm bell to ring when the discharge reaches 48,000 gallons per hour. This bell rings in the house of the main in charge, and also outside the meter house, when the man in charge has to open the byepass valve and the excess above this quantity passes through a storm overflow chamber, where its quantity is measured by a Cippoletti Weir provided with automatic recorder. From this chamber the storm water passes direct to the Farm.

The ordinary dry weather flow passes first into detritus tanks of 10·1/3 hours capacity of the present flow, and 8 hours of the future flow.

Each tank is 35 metres (115 feet) long by 8 metres (26 feet) wide and an average of 2·35 metres (7·71 feet) deep and is divided into four compartments by cross walls. These compartments

have semi-pyramidal bottoms sloping towards the dividing wall, and at the centre of each a 9″ sluice valve is provided for the easy removal of the sludge.

Two 24″ by 12″ penstocks are provided at the inlet to each tank, and reinforced concrete hoods are constructed over each inlet to allow of an undisturbed discharge below water level.

The sludge pipe crossing from the detritus tanks is taken through the wall dividing the two tanks, and the sludge outlet from these tanks discharge into it.

On each side of the division wall, reinforced concrete screen channels are constructed for the easy and convenient removal of screen. There are also connected to the sludge pipe vertical cast-iron pipes.

From the sedimentation tanks, the sewage is led by a channel to the dosing tanks supplying the percolating filters.

This tank has a capacity of nearly 900 gallons, and is provided with an Adam's 20 inch by 6 inch low draught syphon, ensuring a quick discharge on to the filters beds.

The percolating filters, of which there are four, are circular in shape and each of 100 feet in diameter, and are arranged so that they can be used singly or in any combination. They are built on a floor of concrete sloped to a draining channel down the centre of each filter. The average depth of the filters is 5 feet, and the average depth of the filtering medium is 4′-9″. The total contents of the four filters is 5,528 cubic yards, and the rate of flow of the present dry weather flow through the filters will be 110 gallons per cubic yard of medium per day, and for the future dry weather flow, the rate will be 145 gallons per yard cube of medium per day.

The medium will be hard over-burnt bricks graded as follows :—

The lowest six inches from 2 inches to 1½ inch, the body of the filters from 1½ inch to 1 inch and the top 0·40 metre (16 inches) will be from 1 inch to ½ inch.

The draining floor is constructed of Stiff's patent floor tiles three inches deep.

The four revolving sprinklers are Adam's cresset distributors.

After leaving the filters, the effluent can either be passed through two humus tanks, having together a two hours' capacity of the total flow, or can be passed through a channel constructed on the dividing wall directly to the main distributing carrier leading to the Farm.

The humus tanks are each 15 metres (49·2 feet) long by 5 metres (16·40 feet) wide by an average of 1·575 metre (5·2 feet) deep divided into three compartments by low cross walls, and each compartment is constructed with a pyramidal bottom and central sludge outlet.

The area of the Farm proposed to be eventually cultivated will be about 70 feddans of which it is proposed to lay out 20 feddans for the present use.

The original average level of the land in which the Farm is to be constructed was 19·10 Suez Canal Company's datum, or 0·50 metre (1′-7½″) above average subsoil water level.

It is proposed to fill up the level of the land to an average level of 19·68 metres or 1·08 metres (3′-6½″) above the subsoil water with sand and mud from the lake shore, mixed with soil from the Sewage Transport Company's tip.

On the boundary facing the sea an embankment will be constructed to carry a wall and the main distributing carrier commanding the Farm. This will also afford a screen and protection from the prevailing winds. This bank will be made about 0·80 metre above the level of the land to be cultivated. A belt of trees will be grown at the foot of the bank to afford further protection to the growing crops, and cross belts will be planted between each plot as shown in Plate No. 68.

The works were started in September 1913 and completed about the end of 1915. In August 1914 practically the whole of the works were closed down for 6 months, owing to one of the principal contracting firms having to stop work through the outbreak of war, and the consequent increased difficulty of getting

materials from Europe and of the general financing of their work. Eventually the Egyptian Government decided to take the work over and complete it departmentally, and this has been done successfully.

The sewage farm promises as in Cairo to pay all its upkeep expenses. The whole money for the scheme has been found for the Port Said Municipality by the Suez Canal Company on easy terms. The total cost of the scheme was estimated approximately at £170,000. The whole work has been completed within the estimate. The cost per head of estimated population is £2·5, slightly more than the Cairo Scheme.

THE DRAINAGE OF MANSOURAH.

The town of Mansourah is situated on the banks of the River Nile, about 70 miles from Cairo, and is celebrated for its equable climate. It serves a large agricultural district and is one of the most important cotton centres in the Delta.

The population of the town in 1914 was estimated to number 48,000, of which 3,000 only are Europeans. In most large Egyptian provincial towns there is a distinct European quarter consisting of good-class houses inhabited by people with at least European habits, but at Mansourah no such quarters exist, and good-class houses occur side by side with very mean dwellings. This adds largely to the difficulty of planning a satisfactory drainage scheme.

The rainfall is small, and rarely exceeds 1″ in the year, though that amount often occurs in a few heavy showers, causing severe flooding in the lower parts of the town.

The drainage scheme is designed to serve a future population of 75,000, which, it is estimated on the basis of the Census of 1907, the town will attain to in 1940.

The water supply for the town is obtained from the Bahr-el-Saghir Canal, which takes off from the River Nile at the east end of Mansourah, and is pumped and filtered and supplied to the

inhabitants by the Egyptian Government. The present supply is approximately 4,500 cubic metres (one million gallons) per diem or 91 litres (20 gallons) per head of population per diem, and the future supply is estimated at 6,800 cubic metres per diem.

The total area within the municipal boundary of Mansourah is 230 hectares. Of this, 180 hectares is at approximately one level, and must be drained on a sectional system, while 150 hectares, owing to a slight fall from the river, can fortunately be drained by gravitation. Therefore the Author decided on a combined scheme, partly of the sectional system by compressed air, and partly by gravitation.

The level of the subsoil water is only a few feet below the surface of the ground, and deep sewer trenches are therefore very inadvisable.

The 180 hectares on the sectional system are divided into six areas, the sewage from which is lifted and delivered to the pumping station by ejectors, and so passed on from there to the disposal works through a cast iron sealed sewage main.

Plate No. 69 shows the general plan and scheme. No. 7 station is the main pumping station into which the area 150 hectares, between it and the river is drained by gravitation. The sectional pumping areas, Nos. 1, 2, 3 and 4, are situated to the west of this area and Nos. 5 and 6 to the east, the whole being coloured pink on the plan. The sewage from ejector No. 1 is lifted and gravitates to ejector No. 2. It is there re-lifted, together with the sewage from the area served by ejector No. 2, and passes into a gravitation sewer through which it flows to the pumping station. Into this gravitation sewer is also lifted the sewage from ejectors 3 and 4.

The gradient of this sewer has the same hydraulic gradient as a cast iron sealed sewage main would have had, calculated on a velocity of 3 feet per second. There is therefore no more work thrown upon the pumps by lifting the sewage into the gravitation sewer than would have been the case if they delivered direct to the pumping station, and further, the area drained directly to the

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pumping station without subsidiary pumping is much extended along the line of this sewer because, owing to its size, it is laid at a flatter gradient than is required for the smaller sewers in the different sectional areas.

A similar gravitation sewer is laid from the limits of the sectional area No. 5 to the pumping station. The sizes of the sewers are calculated on the future dry weather flow, the minimum size being 9″. The wet weather flow has been disregarded when calculating the size of the sewers, rainfall occurring so seldom in the year, and because the town is so flat that if the sewers are flooded in one part of the town when heavy rainfall occurs there is no danger of the water overflowing from the manholes in any other area.

The advantages gained are reasonable sized pipes flowing half full for the normal flow, and a saving in the cost in the scheme.

Ventilation is provided by means of the vent shafts at each ejector station and in the houses drainage pipes; no intercepting traps are proposed to be used between the house drains and the sewers.

The 5″ street connection pipes from the sewers to the boundary of the house property are included in the estimates of the cost of the scheme.

Disposal Works.—The disposal of the sewage in the case of Mansourah is a difficult problem, as even a storm-water outfall to the river or to the canal was objected to by the Department of Public Health.

The cost of land in the neighbourhood of the town for a sewage farm was quite prohibitive, being at least £200 per feddan.

The utilisation of a private estate situated about 3 miles to the north of the town, and the pumping of the effluent thereto, was considered, but the impossibility of being able to guarantee the estimated future flow and the difficulty of framing a contract which would safeguard the interests of all parties concerned led to the proposal being abandoned.

There remained only the Mansourah drain. This is a large irrigation drain at a much lower level than the canal, and serves to drain a large area of the agricultural district served by the canal. Before discharging, however, into this drain, the Public Health Department decided that a very highly purified effluent was essential, as several villages on its banks used the water for drinking purposes when the canals in the vicinity are dry. The estimate for this work, therefore, includes a detritus and a sedimentation tank, primary and secondary filters, and a sterilization plant.

Pumping Station.—There are now two new sewage pumps on the market worthy of consideration for small installations. One is the Stereophagus pump, which cuts up the solid matter in the sewage so that it passes through the passages of the pump without difficulty, having a cutting device of a somewhat similar type to that of a lawn mower. The second is a pump known as the Jens Orten Boving pump. In this pump the solids are screened from the Sewage and are transferred from the suction pipe into the delivery pipe of the pump and so discharged. Thus only screened sewage passes through the pump.

The Author has made some experiments with a Stereophagus pump in two installations in Cairo, which have been satisfactory, but he has not had the same opportunity of testing a Jens Orten Boving pump, and under these circumstances has recommended a Stereophagus installation of pumps to be put up at Mansourah.

The estimate for the whole work is £E.130,144. This sum on a population of 75,000, works out at £1-14-8 per head, and is an economical figure when it is considered that the bulk of the sewage has to be lifted twice and all of it once.

At present the work is in abeyance owing to the financial stringency brought about by the present war. The drainage scheme, however, is urgently needed, and it is hoped it will be carried out in the near future.

THE TANTAH DRAINAGE SCHEME.

Tantah is the largest inland town in Egypt, next to the Capital, Cairo. It is situated about 100 kilometres from Cairo on the main line to Alexandria, and is an important railway junction, and the centre of a large agricultural district.

The land is highly cultivated to the boundaries of the town and nothing is wasted. The soil is alluvial for a depth of from 3 to 4 metres, overlaying sand. The present population is 62,000 of whom practically the whole are Egyptians. The potable water supply is derived from the Kassed Canal on the outskirts of the town, from which the water is pumped, filtered, and supplied by a private Company subject to the jurisdiction of the Egyptian Government. The town is naturally divided by a large deep ravine which intercepts it, into two areas, the S. W. Basin, which is also the business part of the town, and the N. E. Basin, which contains rather better class houses, the Government schools, etc. The roads are far from being wholly macadamised, and only a few are laid with tar macadam.

The average rainfall is about 2 ins. (50 m-m.) per annum, and the lower parts of the town are subjected at times to severe flooding.

In consequence mainly of this the Municipality of Tantah submitted in 1910 a scheme of drainage on the combined system to the Egyptian Government, which in approving stipulated that sufficient disposal works should be constructed at the outfall at the same time.

The contract for the construction of the main collector and the subsidiary pipe sewers was let in due course, and the works were proceeded with.

The pipe sewers were satisfactorily laid, but the main collector which was of concrete, having failed from defective design and workmanship the Author was called in by the Municipality to advise and complete the works.

Fig. No. 50 is a drawing of the original design decided on by the Municipality, Fig. No. 51 is the design which the Municipality substituted in place of Fig. No. 50 when that design failed.

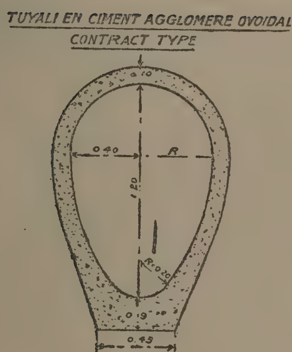


FIG: 50

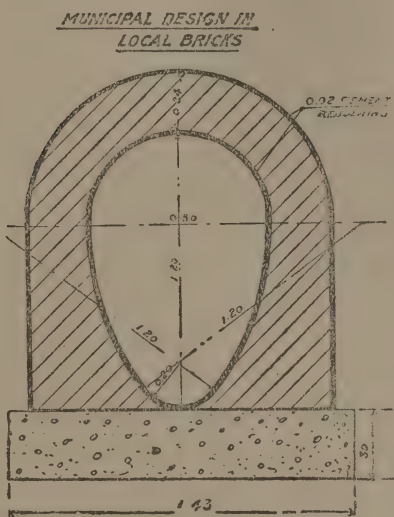
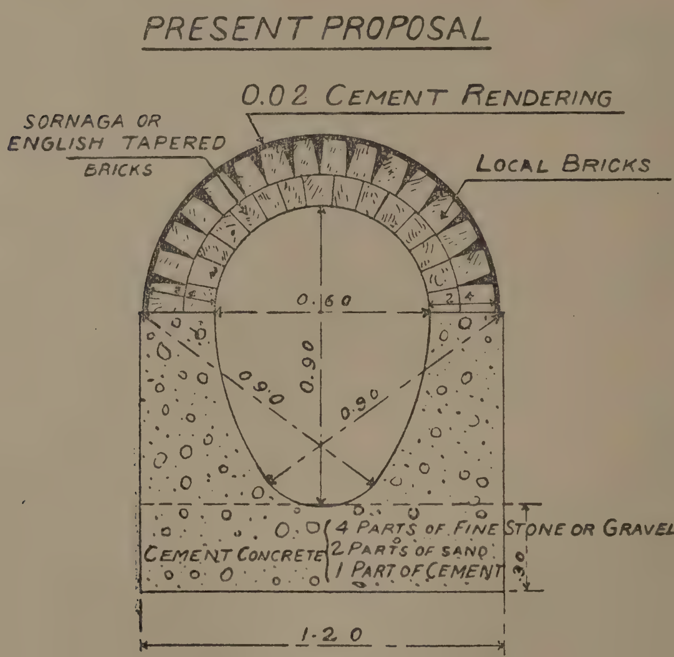


FIG. 51.

The Author disapproved of both the Municipal designs, and substituted design Fig. No. 52, and with that design the collector was eventually satisfactorily completed. The maximum depth at which the collector was to be laid was 6 metres, and at this depth the collector was subjected to an external pressure of between 6 and 7 tons. The original design of the collector would under the best conditions have stood no more than 4 tons.

The question of the disposal works was still left undecided when the original work was completed. The Municipality found that their funds were running low, and that they were not in a position for the moment to spend any sufficient sum on the disposal works. The original intention was to construct a sump with tanks and filters with the addition of three percolating pits. The Author

pointed out that that was entirely wrong, and would not under any circumstances be efficient for any lengthy period. He pointed out at the same time that it was desirable to make use of the purified effluent, if possible, for irrigation purposes, and that the sludge should be so treated that it could be sold as manure. For this purpose it was desirable to consider a process of dealing with the sludge on some lines of the latest and up-to-date method, now



in process of experiment in England and America, and further it was recommended that before proceeding any further with the scheme, the scheme for the whole of the drainage of Tantah should be designed, to be proceeded with as fund permitted.

The above account is interesting, not because of its value as a description of a drainage scheme, but because it shows how

unwise it is to undertake a scheme of drainage without having the advice of an experienced Engineer in that branch of the profession, and also to embark on a scheme which only deals with a part of the town without any idea of what is to be done with the remaining areas, or what the total cost of a complete scheme would be.

CHAPTER XI.

Drainage of Bombay.

The history of the drainage of Bombay is as interesting as it is exceptional, and if, in the light of later experience, it has been found that mistakes have been made, it must be remembered that even so recently as twenty years ago sanitation was to a great extent empirical, and the system of "trial and error" had inevitably to be largely resorted to. Devious although the approach may have been, there is little doubt that Bombay has now arrived at a satisfactory scheme, a study of which, with its great variety of circumstances, must prove of the highest instructive value.

Plate 70 is a copy of an old plan of Bombay as it existed in the year 1672, when it consisted of seven separate islands, which have all now disappeared as such, owing partly to the action of nature, but mostly to the work of man. The red boundary in the plate shews the Island as it exists at the present time. It will be seen that a more difficult place could hardly be found for drainage purposes than this city, with its large area of reclaimed ground below high-water level.

The population of Bombay in the latter part of the seventeenth century is recorded as only 60,000, and the various islands are known to have been inhabited by people belonging mostly to the fisher caste: many traces of old fishing villages, and the descendants of the people themselves still remain in parts of the city.

During the period from 1672 to 1845, in which year the Municipal interests of the city were entrusted to a Board of Conservancy, much was done towards reclaiming the spaces between the islands. There was, however, left for drainage purposes an open ditch, known as the old main drain, which ran from where the Crawford Market now stands, *via* Abdul Rehman Street, Paidhoni, Bapu

Khote Street, and Falkland Road, to the Flats, where it emptied itself into a tidal estuary. No attempts were made to arch over any portion of this drain until 1824, and it was not until 1845 that it was covered even as far as Paidhoni, though the progress after that was comparatively rapid, and by 1856 the arching had been completed up to Bellasis Road.

The size of this old main drain varied. At its commencement in Abdul Rehman Street it was 2 feet by 2 feet. After passing Paidhoni its size was much increased, no doubt because of cross-drains running into it, it being at that point 10 feet 9 inches wide by 4 feet high with a gradient of 1 in 450. In Falkland Road its size was further increased to 20 feet 3 inches by 8 feet 6 inches with a gradient of about 1 in 5,000. In Bellasis Road, where it received the drainage of that part of the island even then known as Byculla, its size was 20 feet 3 inches by 9 feet 10 inches, with a gradient of about 1 in 1,140. From this point it ran over the Flats to the sluices in an open cut. The arching consisted, for the most part, of roughly-dressed stone with side walls of the same material. In many parts there was no foundation, but where any existed it was of rough rubble. This drain carried all the surface water in the monsoon, and all the year round such sewage as was discharged into it by gravitation or by hand. The state of sanitation must, indeed, at this time have been serious, considering the flat gradients and defective construction of the old main drain. It must have been a vast elongated cess-pool, and probably always contained a large quantity of putrefying sewage. This old main drain exists even to this day, though much improved by having been repaired and it parts re-built. It is, perhaps, needless to add that it is now used for storm-water only.

Things had become very serious by 1853, when Mr. Conybeare, a "Superintendent of Repairs," submitted a plan to the Board of Conservancy for alleviating the nuisance resulting from the old main drain. His plan provided for no alteration to the condition of things during the monsoon, but during the dry weather it was

proposed to run the sewage into a pit near Bellasis Road and to lift it after deodorization and use it for irrigation on the Flats. It is on record, and this is hardly surprising, that this did not improve, but rather intensified, the nuisance. Things continued much in the same way until 1860, when a scheme for the drainage of the city was submitted by Mr. Tracey, the Municipal Engineer, who seems to be the first Engineer who seriously attempted to deal comprehensively with the whole of the drainage of the city. He objected to the application of sewage to land, and proposed its discharge by two outfalls into the harbour. In his proposals Mr. Tracey objected to an outfall on the west, as being the windward side, and because he saw the risk of sewage deposit on the foreshore.

The scheme briefly provided for the discharge of the sewage at two points, *viz.*, Wari Bunder and Carnac Bunder. It was proposed to discharge the sewage of Umerkhadi, Girgaum, Kamatipura, Tarwadi, and Nowroji Hill at the former outfall, and that of the Market, Mandvi, and Sonapur at the latter. At Carnac Bunder all the sewers were to discharge into the sea by gravitation only. At Wari Bunder there was to be a low-level as well as a gravitation system. The low-level sewers were to discharge into tanks, whence the sewage was to be pumped into the harbour at ebb-tide. The sewers on the gravitation system were designed to carry both sewage and storm-water, but from the low-level sewers, storm-water was excluded. The whole scheme was to cost Rs. 33,20,000.

Mr. Tracey's scheme was sent to England to the Secretary of State, and Mr. Robert Rawlinson, afterwards Sir Robert Rawlinson, K.C.B., was asked to report on it. Mr. Rawlinson reported favourably in 1863, with some slight modifications. It was accordingly sanctioned by Government in September 1863, and Mr. Tracey was appointed to carry it out, with Captain Trevor as Consulting Engineer. But before much work could be done, Mr. Tracey unfortunately died, while Mr. Wilcox, his Assistant, who succeeded him, also died shortly after.

In the meantime, an agitation was got up against the propriety of placing sewage outfalls so near the populated parts of the city, and Government appointed a Commission, of which Mr. T. Ormiston, the first Port Trust Engineer, was a member. Mr. Ormiston was of opinion that Colaba was the best point for the discharge of the sewage (a view that is now very generally accepted as correct), and that storm-water and sewage ought to be separated, and Government concurring with these views condemned Mr. Tracey's proposed outfalls.

For a year or two no further steps were taken, and the next important epoch in the history of the drainage of Bombay was the scheme prepared in 1866 by Mr. Russel Aitkin, then Engineer to the Municipality, who proposed that the sewage should be discharged into a reservoir at Colaba near the Lighthouse and pumped into the sea on the ebb-tide. Mr. Aitkin objected to a "separate system" as impracticable in Bombay, and therefore provided for the sewage and the storm-water to flow away by the same drains. He proposed a main sewer from Null Bazar to Colaba with large branch sewers from different districts. These intercepting sewers were designed to carry a maximum rainfall of eight inches per diem in addition to the ordinary sewage of the districts to be drained. During the fair season the sewage was to flow by the main sewer to Colaba where it was to be pumped into the sea. During the monsoon the branch sewers were to be cut off from the main sewer, and to discharge the sewage and storm-water into the harbour or Back Bay, the flow being against the gradients. The main sewer from Null Bazar to Colaba was thus during the rains to carry off the sewage and storm-water only from the low-lying district lying between Khetwadi and Bellasis Road. This main sewer was designed to carry off only two inches of rainfall per diem from this low-lying district, and Mr. Aitkin therefore proposed to retain the existing open main drain to receive the surplus, when more than two inches of rain fell in a day.

The whole cost of Mr. Atkin's scheme was 110 lakhs of rupees, the annual working expenses being Rs. 2,50,000. Mr. Russel Aitkin's views at that time regarding the velocity in the sewers strike one as curious in these days of advanced knowledge. In the main sewer the velocity was to be not more than $2\frac{1}{2}$ feet per second when running full with sewage and storm-water, but during the dry weather it was to be only 1 foot or even 9 inches per second, and this was then supposed to be sufficient to prevent deposit in the sewers.

In 1867 Mr. Aitkin's scheme was forwarded to Mr. Robert Rawlinson, who was of opinion that sewage discharged at Colaba would return to the harbour. The natural fall of the Island towards the Flats and Warli indicated to him the true direction for the conveyance of the sewage. He further added that float experiments carried out by one Mr. Jagannath Sadashiv proved that a Colaba outfall would contaminate the harbour.

As regards these float experiments, which were believed in and relied upon for so many years as conclusive evidence that to discharge the sewage at Colaba would be fatal to the interests of the City, it is interesting to note that it was left to Mr. Baldwin Latham during his visit to Bombay in 1890 to discover that the arrows indicating the directions of the floats were wrongly shewn on the plan. That is to say, they pointed to the north instead of to the south and thus erroneously led to the conclusion that the current during the ebb-tide set into the harbour instead of flowing to the open sea. This extraordinary mistake has no doubt been the principal cause of Bombay having its outfall on its western foreshore with all the nuisance that has arisen therefrom.

Mr. Russel Aitkin's scheme, therefore, remained in abeyance, though some works proceeded in the Fort which had its separate outfall near the Mint.

Pending the settlement of the main question of the drainage of Bombay, Mr. Aitkin also constructed a low-level sewer from Bellasis Road to Love Grove, which during the fair season inter-

cepted all the sewage from the old main drain, and conveyed it to a Pumping Station at Love Grove, where it was lifted by one chain, and two centrifugal pumps into the sea. The drainage of Kamatipura was also taken in hand, and brick-sewers and pipe-sewers were substituted for open drains. These sewers, though highly commended then, were afterwards condemned by Mr. Baldwin Latham in 1890.

In 1868 Captain, now Major Tulloch came to Bombay from England, and the Municipality referred the drainage question to him. In November 1868, he submitted his report and advocated the segregation of sewage from storm-water, and was of opinion that whether the sewage was applied to land or discharged into the sea, it should be taken towards the west of the city and not towards the harbour or Colaba. His reasons were that the natural slope of the Island was towards the west, and any discharge towards the east might foul the harbour.

He proposed to pump the sewage at Love Grove and to utilise it on land, or, as an alternative, to carry it back from Love Grove and discharge it at Colaba, if an outfall at that point were approved, though he was personally opposed to this. He was equally opposed to an outfall on the west, but ultimately his own reasoning in meeting the arguments of the opponents to his scheme led him inevitably to that point.

In 1869, Government appointed a Commission, with Mr. A. R. Scoble as President, to consider and report on the drainage and water-supply of Bombay, including a report on Major Tulloch's scheme.

The Commission concurred with Major Tulloch as regards the necessity for a "separate system," but they differed from him on several points, principally the carrying of the night-soil through the sewers and the utilisation of sewage on land.

Plate 71 shews an interesting geological map of the Island of Bombay prepared by Major Tulloch in support of his proposals

to carry the main sewer towards Love Grove, that course running for the most part through made ground.

The report of the Commission, and the financial difficulties in which the Corporation found itself at the time, postponed any serious advance being made with the drainage until 1877, though during the interval some work was done, slowly and casually, as particular nuisances required to be dealt with.

The extension of building operations, however, aggravated the nuisances, and in 1877 they became so intolerable that on the recommendation of the Town Council, the Corporation asked Government to appoint a Commission to advise as to what scheme was the best to adopt for the drainage of the City, and Government responded by appointing four gentlemen with Surgeon-General Hunter as the President. A number of witnesses were examined by the Commission, which issued its report in January 1878, recommending the adoption of Major Tulloch's scheme as slightly modified by Mr. Rienzi Walton, the then Executive Engineer to the Municipality, who advocated the pumping of the sewage into the sea at the Love Grove outfall. This scheme consisted of laying a main ovoid sewer from Carnac Bunder to the Crawford Market to be continued along Sheik Memon Street, Bhuleshwar, Khetwadi, and the Flats to Love Grove, with a branch sewer from the Town Hall to the Crawford Market and another up Clerk Road. A Pumping Station was to be erected at Love Grove to pump the sewage into the sea. The Commission was further of opinion that house-connections would be suitable, and that provided the water-supply was not less than 20 gallons per head per diem, the night-soil might be freely admitted into the sewers, with a recommendation for the enforcement of a standard water-closet, except for huts and inferior buildings where house-connections were impossible. It strongly recommended free ventilation of all sewers, and the separation of storm-water from sewage.

The drainage of Bombay, as now carried out, has in the main closely followed these recommendations.

The report of General Hunter's Commission was an important one, as it marks the commencement of an entirely new era regarding the drainage history of Bombay.

The Corporation took the matter up seriously and in March 1878 sanctioned the scheme. The Government of India were asked to give a loan of Rs. 60 lakhs, most of which was to be devoted to its execution. The loan was refused, and in September 1878 the Municipality itself raised a loan of 27 lakhs in Bombay, and in December of the same year the work was commenced under the supervision of Mr. Rienzi Walton, the Executive Engineer, who was placed on special duty for this purpose. The works immediately taken in hand were the main sewer from Carnac Bunder to Love Grove, certain branch pipe sewers, a Pumping Station with new plant at Love Grove, and a new outfall sewer.

In May 1881 the main sewer, as it now exists from Carnac Bunder to Love Grove, was completed. It is ovoid in shape and of the following sizes :—

From	To	Sizes.	Distance in Miles.
Frere Road (Carnac Bunder).	South end of Sheik Memon Street.	2′-6″×3′-9″	0·52
South end of Sheik Memon Street.	Cawasji Patel Street ..	2′-8″×4′-0″	0·78
Cawasji Patel Street ..	Junction of Khetwadi Back Road and Khetwadi 10th Lane.	3′-4″×5′-0″	0·51
Junction of Khetwadi Back Road and Khetwadi 10th Lane.	Junction of Grant Road and Falkland Road.	3′-10″×5′-9″	0·14
Junction of Grant Road and Falkland Road.	Clerk Road Crossing ..	4′-8″×7′-0″	0·35
Clerk Road Crossing ..	Love Grove	5′-4″×8′-0″	0·95
		Total ..	4·25

The cost of the whole of this work amounted to five lakhs of rupees.

By 1880 the outfall sewer from the Pumping Station to an outlet chamber on the foreshore had been completed at a cost of $2\frac{1}{2}$ lakhs. This is a double barrelled masonry sewer, each barrel being 3 feet 6 inches in diameter. From the chamber are laid two parallel 36-inch pipes, running into the sea 6 feet below low-water spring tides. These pipes were not laid until the end of 1881.

Meanwhile branch pipe sewers had also been laid, connecting with the main sewers, in various streets, at a cost of $2\frac{1}{2}$ lakhs.

The Pumping Station at Love Grove has a history of its own. The first erected, as already stated, in 1867 by Mr. Russel Aitkin contained two centrifugal pumps and a chain pump. In 1869, the flow of sewage was considerably increased, and in 1870 two new chain pumps were erected and one of the old centrifugals removed. In 1872, a further alteration was made, the other old centrifugal pump being removed and a new direct-acting centrifugal pump put in its place. The four pumps, namely, three chain pumps and one centrifugal, were together capable of lifting $20\frac{1}{2}$ million gallons per diem, though not more than 8 million gallons per day found its way to the pumping station. From time to time, the pumps gave trouble, and finally it was decided to erect a new Pumping Station and plant, which was included as a part of Mr. Walton's scheme sanctioned by the Corporation in 1878. The new station was completed in 1884 at a cost of a lakh of rupees, and four engines and pumps were erected therein at a further cost of a lakh and three-quarters. These engines and pumps worked until 1890, when they were condemned by Mr. Baldwin Latham as being extremely inefficient and thoroughly worn-out. A new engine-house was then constructed near the old one, and four Worthington direct-acting triple-expansion engines and pumps made by Messrs. James Simpson & Co., London, capable of lifting 15 million gallons each per diem, together with four Babcock and

Wilcox boilers, were erected at a cost of four lakhs of rupees, these commenced to work in 1893.

It has already been stated that brick and pipe sewers were laid in Kamatipura by Mr. Russel Aitkin, and in 1870 the district was declared by Mr. Thwaites, who succeeded Mr. Aitkin as Engineer, as one of the best drained districts. In 1877, however, the attention of the Corporation was directed to the insanitary state of the district and Mr. Walton was asked to report on it. Mr. Walton reported in 1880 that the system of drainage in Kamatipura was a complete failure : the joints of the pipe sewers were made of clay, storm-water and sewage were discharged into the same channels, and the brick sewers were directly connected with the old unventilated Umerkhadi sewer. He submitted a scheme for the re-sewerage of Kamatipura, which provided for the re-laying of the pipe sewers and connecting them with the new main sewer at the junction of Grant Road and Falkland Road by means of a new 2 feet 6 inches by 3 feet 9 inches branch ovoid sewer. It also provided for the exclusion of all storm-water from the sewers. The scheme was approved and sanctioned at a cost of a lakh and a half of rupees, and the works were completed in 1883.

In the same year a branch ovoid sewer, 2 feet 6 inches by 3 feet 9 inches, was constructed along Clerk Road from the main sewer to Jacob Circle at a cost of Rs. 30,000, which was in the next two years extended to opposite the Victoria Gardens at a further cost of Rs. 33,000.

In 1885, the Queen's Road sewer, which runs from opposite the B. B. & C. I. Railway Marine Lines Station and joins the main sewer at Khetwadi 10th Lane, was completed at a cost of a lakh and a half of rupees. This sewer intercepted all the sewage which was being discharged into Back Bay.

Other drainage works were also at this time pushed on rapidly, the Ripon Road ovoid sewer, 2 feet 6 inches by 3 feet 9 inches, having been completed in 1886 at a cost of Rs. 60,000 ; the Mint Road sewer, also 2 feet 6 inches by 3 feet 9 inches from the Mint

to the Crawford Market, was completed in the same year at a cost of Rs. 90,000; and in 1890, the pipe sewers in Agripada were laid at a cost of one lakh.

House connections were also pushed forward in various districts, the Corporation spending some fifteen lakhs of public money on these connections.

In 1889, complaints were received of nuisances existing in Marine Lines—a part of the City principally occupied by the Military—and the same being attributed to the new pipe sewer, Government appointed a Committee to inquire into the matter. The Sanitary Commissioner to Government, who was one of the Committee, made an adverse report on the sewerage of the City generally; considerable discussions also arose as to the suitability of the sewage outfall at Love Grove; and the Corporation on the recommendation of Sir Charles Ollivant, the then Municipal Commissioner, sought the advice of Mr. Baldwin Latham on the question of the drainage of the City, both present and future.

Mr. Latham came to Bombay in 1890, and his visit was a very successful one and resulted in the Corporation obtaining a useful report known as the "Sanitation of Bombay." He reported that the different sections of the main sewers were properly designed in regard to the population they were intended to serve, but that he found considerable silt in them, mostly due to the inefficiency of the pumping engines at Love Grove, which he condemned as worn out. He found that the pipe sewers had been well laid, and pronounced the jointing equal to any he had seen elsewhere. He condemned the outfall at Love Grove and shewed the fallacy of the float experiments of Mr. Jagannath Sadashiv and proved that an outfall at the Colaba point was the best. As, however, the main sewers had already been laid with a fall towards Love Grove, he recommended that all the sewage should first flow to Love Grove and be there pumped into a high-level gravitating sewer running from Parel to Colaba and discharged at the latter place at ebb-tide only beyond the Prongs Light House.

The Corporation sent a copy of the report to Government to ascertain if they would allow an outfall at Colaba as recommended by Mr. Latham. The Government appointed a Commission who examined, among other witnesses, Mr. Baldwin Latham, who admitted that if, for financial or other reasons, the outfall could not be placed at Colaba, the existing outfall was the next best. The Commission reported that the cost of Mr. Latham's proposals was prohibitive, and that Love Grove was the second best site for an outfall, and the Government declined to sanction the new proposals.

In 1893, although a large amount of the island had been drained, there still remained several populated parts of the City where no drainage of a satisfactory kind existed. These districts were Colaba, Mazagaon, Malabar Hill, Chinchpokli, Parel, and the northern part of the Island.

Colaba was the first of these districts to engage the attention of the Municipality. The discharge of sewage at different points into the harbour created an intolerable nuisance, and loud complaints were made by the public. It could not, however, owing to the configuration of the land, be drained by gravitation only to the sewers already laid, and some sectional system had therefore to be resorted to. It was at first proposed to lift the sewage at some convenient point by direct-acting pumping, but the Municipality failed to obtain any suitable site for a pumping station. Both the Port Trust and the Government, who are large land-owners in the district, declined to give land for the purpose. After great discussion, it was ultimately decided in 1893 to drain the district on the Pneumatic System. The works were designed and carried out by the late Mr. J. W. Smith at a cost of eight lakhs of rupees. They provide for a prospective population of 28,000 people, the present population being about 18,000.

The district is divided into five blocks, each having an Ejector Station as shewn in Plate 72.

Nos. 1, 2, and 3 Ejector Stations have each two ejectors of 500 gallons capacity each, No. 4 Ejector Station two ejectors of

300 gallons capacity each, and No. 5 Ejector Station two ejectors of 100 gallons capacity each. One ejector is sufficient to cope with the sewage in each block, the other being held in reserve. The stations are built of bricks set in cement mortar, plastered on both sides with cement.

The compressed air is supplied to the ejectors from an Air Compressor Station, erected in a convenient position near the Arthur Basin. In this are placed three compound non-condensing engines, each of 40 indicated horse-power, with two marine boilers of the type known as the "Dry Back Tubular." Two engines and one boiler are sufficient to deal with the maximum requirements of the whole district, the third engine and the other boiler being a stand-by. Each of the engines is designed to deliver 450 cubic feet of free air per minute, compressed to 22 lbs. above atmospheric pressure.

The compressed air is delivered into an air-receiver, placed outside the engine-house, having a capacity of 800 cubic feet. The air main is coupled up to the receiver, and supplies air to each of the stations by means of suitable branch pipes.

A sealed sewage main is laid from No. 3 Ejector Station to the Wellington Fountain at the north end of the Colaba district, with branches from Nos. 1 and 2 Ejector Stations, and discharges into a long chamber near the Fountain. From this chamber the sewage flows into the gravitation pipe sewers. The use of the chamber is to receive the contents of the sealed sewage main, should they be required to be suddenly blown out in the case of an obstruction taking place in the main. No. 4 Ejector Station discharges its sewage through a short length of sealed sewage main into the head of a sewer gravitating to No. 3 station, where it is all re-lifted, while No. 5 discharges also through a short length of sealed sewage main into the sewer gravitating to No. 4, where the sewage is re-lifted and sent to No. 3, where it is again re-lifted. The double lifting of the sewage of No. 4 sub-district and the treble lifting of that of No. 5 has been adopted as being economical, for

the reason that to force the sewage of these sub-districts, which is comparatively small in quantity, through a rising main from one end of Colaba to the other, would require compressed air at a much higher pressure than necessary for the other three stations, where the greater part of the district gravitates.

The drainage of this district was completed in 1895, and house-connections were immediately taken in hand, not on this occasion at the cost of the Corporation, but of the owners themselves, and completed in the following year.

The Pneumatic System at Colaba gave such satisfaction that it was decided in 1897 to extend the system to other districts, *viz.*, Mazagaon, Parel, Chinchpokli, the Old Race Course, and Malabar Hill.

It was considered more economical to provide at one station the air compressing machinery required for all these districts than to construct separate installations for each of them. The Corporation, therefore, sanctioned in 1897 the construction of an Air Compressor Station at Love Grove to the north of the Pumping Station, and the erection of the air compressing machinery and the laying of air mains capable of dealing with the sewage of all the above districts, at a cost of 8 lakhs.

This compressor station contains four horizontal triple expansion condensing engines. Each engine has three air compressing cylinders, the pistons of which are coupled direct to the steam pistons. Two of the engines indicate 220 horse power each on a full load, and are each capable of compressing 2,466 cubic feet of free air per minute to a pressure of 23 lbs. above the atmosphere. The other two engines are each half the size of the above.

The first cost of the two smaller engines was greater than that of one of the larger size, but in a large installation of this kind where the day and night loads vary considerably, it is always advisable to have two sizes of engines in order to avoid the loss which would be occasioned by working a large engine much below its maximum speed.

The two larger-sized engines, or one of the larger and two of the smaller-sized engines when working together are capable of lifting 14,000 gallons of sewage per minute to heights varying from 17 feet to 44 feet dynamic head.

Steam is supplied from three Babcock and Wilcox water tube boilers, each having 1,426 square feet of heating surface, and capable of working up to a pressure of 200 lbs. per square inch.

A Green's Fuel Economiser of 168 tubes is fixed in the main flue from the boilers for the purpose of heating the boiler feed water.

Simultaneously with this work, the sewerage of the Mazagon District was also taken in hand. Here two ejector stations have been constructed, one containing two ejectors of 1,200 gallons each and the other two of 250 gallons each. In this district the ejector stations have been built of cast-iron tubbing, owing to the presence of much subsoil water. The work was completed in 1899 at a cost of 3½ lakhs.

In 1900-1901, a further extension of the Pneumatic System was sanctioned for the districts of Chinchpokli and Parel. There are two ejector stations in the former district, and three in the latter. Plate 72 shews the positions of the five ejector stations, and the pipe sewers, air mains, and sealed sewage mains.

Ejector Station No. 1, in the Chinchpokli District, is built of brick-work in cement and contains two ejectors of 1,000 gallons each, while that in No. 2 is of cast-iron tubbing, containing two ejectors of 1,200 gallons each. The ejector stations Nos. 1 and 3 in the Parel District are brick chambers, while No. 2 is of cast-iron tubbing. No. 1 station contains two ejectors of 700 gallons capacity each, No. 2 contains two ejectors of 1,000 gallons capacity each, and No. 3 contains two ejectors of 600 gallons capacity each. The compressed air is supplied to these stations from the Air Compressor Station at Love Grove. All the sewage is discharged into existing gravitation sewers and flows to the Pumping Station at Love Grove. The cost of sewering these two districts has been about 9 lakhs, and the works were completed by the middle of 1903.

There now remains only the drainage of Malabar Hill, the Elphinstone Estate, the Agripada Estate, and the North of the Island.

The Agripada and Elphinstone Estates are to be drained on the Pneumatic System, the compressed air being supplied from the present station at Love Grove. Each district will have two ejector stations, with duplicate ejectors in each. The work of sewering the Agripada Estate has been sanctioned, and has since the above was written been completed.

As regards Malabar Hill, the proposals are to deal with half the sewage on a biological system, to drain about a third of the district to the north on the Pneumatic System, and the remainder near Chaupati by low-level sewers and a small pumping plant.

Plate 74 shews the three divisions of the district and the drainage arrangements in each sub-district. No. 1 is that which is to be drained by Tanks and Filters, the effluent being discharged into the sea. The prospective population is taken at 8,000 and the daily flow of sewage at 300,000 gallons. The sewage is to first flow into a closed Liquefying Tank having a capacity of one day's flow of sewage. This tank will be 160 feet by 50 feet by 6 feet, and so constructed that it can be cleaned in sections. Connected with the tanks will be duplicate catchpits and screening chambers to arrest such materials as rags, road detritus, and other mineral matter in the sewage. The effluent from the Liquefying Tank will flow on to a series of 6 contact beds for its final purification, each of the beds being 110 feet by 32 feet by 3 feet. These beds will be filled with 1 inch cube metal. Besides further purifying the Liquefying Tank effluent, the contact beds will serve also as a storage tank when the tide is above the level of the beds. The installation is to be built on the Western Foreshore with a wall protecting it from heavy seas.

No. 2 sub-district is to be drained on the Pneumatic System, an ejector station containing two ejectors of 250 gallons capacity each being placed in Warden Road near Scandal Point. The

compressed air will be supplied from Love Grove and the sewage lifted and discharged into an existing gravitation pipe-sewage, a few hundred feet to the north of the ejector station.

The sewers in No. 3 sub-district will gravitate to a point on the Chaupati Estate, where the sewage will be lifted by means of an oil engine and pumps into a gravitation sewer.

The total cost of drainage of the three sub-districts is estimated to be :—

Sub-district No. 1	Rs.	3,19,439
Do ,, 2	,,	1,99,635
Do. ,, 3	,,	1,20,874
Total	Rs.	6,39,948

Plate 75 shews the parts of the Island drained on the gravitation system and those on the Shone System.

In the autumn of 1899 the late Mr. W. Santo Crimp, at the request of the Corporation, visited Bombay to advise on the various drainage questions, particularly that of the disposal of the surface-water of the City and that of the discharge of sewers at the Love Grove Outfall. For a long time loud complaints had been made by the public regarding the sewage discharged at the Love Grove Outfall, the smell being perceptible, particularly at the time of the ebb-tide, all along the western foreshore of the Malabar Hill. The history of the outfall has been touched upon in the early part of this chapter, where it has been pointed out that a clerical error has been the cause of years of trouble and nuisance to a part of the Island which should have been, in regard to its healthy condition, the most desirable residential quarter of the City.

Mr. Santo Crimp caused a series of float observations to be taken at Love Grove, the results of which are very interesting. They show without doubt that the sewage discharged on an ebb-tide flows on the surface of the sea and is carried by the tide well down and towards the coast in the direction of the Malabar Point.

On the other hand a flowing tide took the floats well out into the sea and up the coast.

The following remedies have been proposed by Mr. Santo Crimp to overcome the nuisance during the ebb-tides :—

(1) The extension of the present outfall into deeper waters ;

(2) Treating the sewage discharged during the first four hours of the ebb-tide with electrolyzed sea-water ;

(3) Treating the sewage discharged during the first four hours of the ebb-tide with Permanganate of Potash ;

(4) An extension of the outfall sewer to Worli Point, discharging at that point all the sewage during ebb-tide, and at the Love Grove outfall during the flowing tide.

While the Author was in England in 1903, he was deputed by the Bombay Corporation to visit several Disposal Works in England and to submit his views on the question of abating the nuisance arising from the Love Grove Outfall. He visited several towns and cities in England and submitted a report to the Corporation, giving an account of the disposal works at those places, and expressing his views on the particular question at issue.

He pointed out that while in all well sewered towns in England, with sea outfall, crude sewage is discharged into a depth of water not less than 18 feet, and at a great distance from the shore, the present outfall at Bombay discharged nearly 30 millions of gallons of sewage per diem into a minimum depth of 6 feet of water, and close to the shore.

He gave it as his opinion that if the sewage were chemically treated and precipitated, no alteration in the present outfall would be necessary ; but he at the same time pointed out, on the basis of experiments carried out at Manchester, that the cost of the chemicals was prohibitive. The expenditure on the cheapest chemical material, *viz.*, Chlorine, would in Bombay, on the Manchester basis, be 26 lacs of Rupees per annum. He also pointed out that there was no way of simply deodorizing the sewage of Bombay. In all cases where sewage is chemically treated in the British Isles,

it is done to precipitate the solids and to that extent deodorization is combined with it, but in no case is deodorization alone performed.

The Author is indebted for the information contained in the subsequent pages to Mr. N. Maughan, M. Inst. C.E., who has been in charge of the Bombay Drainage since 1906.

The sewerage work in No. 1 Sub-District, Malabar Hill, was completed before the rains of 1906, and the installation has been working ever since satisfactorily, though the sea protection wall which was damaged during the rains of 1906, had to be rebuilt according to a modified design, and it was further protected by the construction of piers in front of the wall for breaking the sea waves.

The designs for the sewage of No. 2 Sub-District and No. 3 Sub-District were also materially revised in the latter part of 1906. It was originally intended to drain the whole of No. 2 Sub-District on the Pneumatic System with only one Ejector Station in Warden Road. This, however, involved very deep excavations in rock, and therefore this Sub-District was divided into two Sub-Districts, one having an Ejector Station, containing two Ejectors of 100 gallons each, in Nepean Sea Road, and the other, with an Ejector Station containing two Ejectors of 250 gallons each, in Warden Road near Scandal Point. The Ejectors in Nepean Sea Road discharge the sewage through a sealed sewage main into the head of a sewer gravitating to the Ejector Station in Warden Road, where it is relifted and discharged through a sealed sewage main into the existing gravitation pipe sewer flowing towards Clerk Road.

The Sub-District No. 3 has also been drained on the Pneumatic System, an Ejector Station containing two Ejectors of 400 gallons each being placed at Chowpatty. The works in the Sub-Districts Nos. 2 and 3 were commenced in the early part of 1907 and were finished in the middle of 1909.

Steel air mains and steel sealed sewage mains were used as an experimental measure in connection with the Ejectors in these Districts. While the steel air mains have given no trouble, the

steel sealed sewage mains have shown signs of wear, owing to the thinness of pipes, the scraping action of the silt and the corrosive action of the sewage. It has ultimately been decided to replace these steel sewage mains with cast-iron pipes.

The total cost of draining the whole of the Malabar Hill District has been Rs. 4,46,500.

In 1910 the work of constructing the storm-water drains for the high lands of the City, lying between Bhoiwada Cross Road and the Byculla Bridge, and east of Sopari Baug Road and Parel Road, was undertaken with a view to prevent the storm waters from these high lands flowing on to the low lands and flooding the latter. The high-level drain commences at the Junction of Sopari Baug Road and Elphinstone Road with a 6 feet diameter drain, and runs down the whole of Sopari Baug Road, it then turns eastwards towards Parel Tank Road, along Parel Tank Road and Reay Road, ultimately discharging into the harbour at the Lakri Bunder, where the drain consists of two barrels, each 14 feet in width and 9′-6″ in height. Another branch commences from the foot of the Byculla Bridge and runs thence northwards along Parel Road and then along Connaught Road, joining the main drain at the Junction of Connaught Road and Reay Road. The size of this southern branch is 3′-6″ in diameter at the head and 9 ft. diameter at the end. The construction of these high-level drains has made immense improvement regarding the surface drainage of this part of the Island, and the work extended over nearly four years. The cost of all the drains mentioned above was 17½ lakhs of rupees.

In 1913, the work of sewering the Elphinstone Reclamation District was taken in hand. This district lies on the east of the G. I. P. Railway and between Carnac Bander Road and Wari Bander Road. The district has been sewered on the Pneumatic System, with an ejector Station opposite the Prince's Dock, containing three Ejectors of 750 gallons each. The sewage is ultimately discharged into the Carnac Bander ovoid sewer. The work was

completed before the rains of 1914, and the total expenditure was Rs. 2,17,000.

During the last few years, it has been found necessary to make very large alterations and additions at the Love Grove Pumping Station. With the increased quantity of sewage, it was found that the Worthington engines were not satisfactorily coping with the sewage. Owing to the sumps of the pumps being at the same level as the bottom of the main sewer at Love Grove and the impossibility of running the engines at variable speeds, there was serious surcharging in the main sewers.

The matter was very carefully considered for a long time and ultimately under the advice of Mr. G. Midgley Taylor, M. Inst. C.E., Consulting Engineer to the Bombay Municipal Corporation, it was decided to instal four new engines in an entirely new house. These engines are beam engines with vertical plunger pumps, each capable of pumping a maximum of 15 million gallons a day. Each of these engines is provided with a governor and variable steam cut off, so that the speed of each engine can be varied and the pumps run at the rate at which sewage is reaching the works. The sumps in the new engine house are 10 feet below the level of the bottom of the main sewer, so that a free flow at the end of the main sewer at Love Grove is ensured.

Steam for these engines is supplied by four Babcock and Wilcox water tube boilers installed in a new boiler house alongside the engine house. The boilers are provided with superheaters and chain grate stokers.

It has also been found necessary to instal a dredging and screening plant, Plate No. 76, so as to remove the detritus and silt from the sewage before it enters the new engine house. These are contained in a new building. The dredgers are in duplicate and are of the bucket type, working on endless chains and driven by electric motors. The sewage after running through the dredging portion of the house passes through four coarse vertical screens and thence through four sloping finer screens. On the latter

screens work electrically-driven rakes, see Plate No. 76, for lifting up the materials caught on the screens which are thence removed by an endless belt to outside the house, where both the dredgings and screenings are disposed of.

Both the dredging and screening plant and the pumping installation are working very satisfactorily. The work was commenced in the beginning of 1909 and was practically completed in the beginning of 1913, and has cost nearly 17 lakhs of Rupees.

In connection with the new pumping plant, it has also been decided to construct a low-level sea outfall at Love Grove, which is estimated to cost some 25 lakhs of Rupees and this work which has already been taken in hand is progressing satisfactorily. Two steel tubes, each 6 feet in diameter, will discharge the sewage about half a mile from the shore.

Recently it has been decided to bring more water into the City by duplicating the Tansa Main, and it is estimated that another 20 million gallons of water will be brought into the City. To cope with this additional supply, it has been found necessary to duplicate some sewers at a cost of 12 lakhs of Rupees. A portion of the duplication of the sewer from Love Grove to Clerk Road has already been constructed, and another portion, from Clerk Road to the Junction of Lamington Road and Gilder Lane, is now in hand, and it is expected the whole of the duplication will be completed in the next two years. In order to deal with the increased flow of sewage and the ever increasing flow from the monsoon rains further extensions of pumping machinery are in contemplation and a design has been submitted by Mr. G. Midgley Taylor which involves the erection of four centrifugal pumps, each connected direct with an electric motor placed vertically over the centrifugal pump.

Each of these pumps is designed to throw fifteen million gallons per diem and the current for the motors will probably be purchased from the Tata Hydro-Electric Company.

Regarding the sewage of the north of the island, the Corporation have finally resolved to have another pumping station on the Tulsi Pipe Road, midway between Dadar Road and Elphinstone Road, where all the sewage, from the Mahim District and from the northern portion of the Island east of the Railways, will gravitate. The sewage, after being lifted at this pumping station, will be discharged into the new Love Grove Low-Level Outfall Sewer through a rising main, to be laid from the new pumping station to Love Grove.

It will be seen that much satisfactory work has of recent years been done to the Bombay drainage, some of it on schemes projected before 1906 and some on new works.

In the north of the island it will be noted that a separate pumping station has been decided on which will deal with the whole of the drainage of that district, but which the Author proposed should discharge on the ebb-tide into Mahim Bay. The new arrangement is undoubtedly preferable, but the small population in this area did not warrant the expenditure in the Author's time.

The drainage of the Island of Bombay can now, both for sewage and surface water, be considered to be practically completed.

Commencing in 1879 it has taken nearly forty years to reach this point. During these forty years, knowledge in Sanitary Science has increased by leaps and bounds, and at a later date a full and detailed account of the development of the Bombay drainage will be of considerable interest to all Sanitary Engineers.

It will be seen from this description that the drainage of Bombay presents an exceptional variety of different systems, and accordingly there can be few cities, if any, in India of greater interest or higher educational value to students of sanitation.

CHAPTER XII.

Sewerage of Calcutta.

THE City of Calcutta is situated in the Lower Gangetic delta on the east bank of the River Hooghli.

The name Calcutta appears to have been corrupted from Kali-kshetra (the field of Kali), the sacred God of Hindoo legend, through whom the spirit of Sati manifested itself after she had caused her spirit through a family quarrel to leave her body. After the body had been smashed in pieces by Vishnu, the Creator, the little toe of Sati's right foot is said to have fallen on the site of Calcutta.

The city is said to have been founded in 1690 by a merchant of the East India Company named Job Charnock, who with his associates considered the site sufficiently above the surrounding swamps to be suitable for a settlement. The visitors anticipating trouble, shortly after settling, built a fort which was named Fort William (in which was situated the historical Black Hole) to protect their property, and the present magnificent city has gradually developed round the site. No vestige of this fort now remains. A new Fort William has been built further south. The City Port dues in the year 1700 were about Rs. 500. The value of its import and export "sea-borne foreign trade" in 1912-1913 amounted to 6,135 lakhs and 9,461 lakhs of rupees respectively. Its Municipal revenue in 1694 was Rs. 900; it is now, in 1915, 116 lakhs or (say) £773,256 (one lakh being equivalent to £6,666–13–4).

In 1727 a Corporation of 9 Aldermen and a Mayor was appointed to look after the Municipal affairs of the settlement, but it appears to have done little for its sanitation, for in 1780 we are told that Calcutta was little better than an undraineed swamp,

with filthy roads and streets, and with drains and ditches reeking with putrifying matter.

Between 1794 and 1836 it appears to have been the custom to raise funds for the improvements of the town by means of lotteries, 10 to 12 per cent. of the amount collected being retained for improvement works and expenses, and the rest distributed in prizes. From 20 to 30 lakhs of rupees appear to have been obtained in this manner. New roads were constructed from the north to the south of the city and east to west, until in 1836 the total length of roads reached 170 miles. A pumping station was built at Chandpal Ghat, on the bank of the Hooghli, and the unfiltered river water was pumped and conveyed by means of conduits along the side of some of the metalled roads for road watering. Several large squares were laid out with tanks in the centre, many of the streets were lighted with oil lamps, and open drains were improved. In 1836 the lotteries were abolished through public opinion in England becoming unfavourable to this method of raising funds for Municipal work. There are now over 292 miles of metalled streets and roads, lighted with about 11,930 gas lamps and 1,758 oil lamps.

It was not until about 1856 that the authorities appear to have awakened to the absolute necessity of providing the city with a pure water supply, and a proper system of under-ground drainage. The water previously had been obtained from the river opposite the city, and from wells and tanks, the inhabitants storing the water in chatties and precipitating the suspended matter by the aid of alum. The foul drainage passed away in filthy open drains.

By the Acts of 1856, and subsequently, the Justices of the Peace were required to carry out complete systems of pure water supply and drainage; they were also empowered to levy rates and borrow money for such work. Schemes for both works were prepared and approved with little delay. The water supply was obtained by pumping from the River at Pulta, 20 miles above Calcutta, where the water was free from salt and possible pollution from

sewage of the City. The supply commenced in 1870 at 6,000,000 gallons per day equivalent to 15 gallons per head of the population, which appears to have been about 400,000 at that time. The water was pumped from the river into settling ponds, filtered, and brought by gravitation through a 42″ cast iron main, 12 miles, to a reservoir in the city, from which it was distributed through branch cast iron pipes along the principal streets. Cast iron pipes were also laid for the distribution of unfiltered water from the city pumping station, since dismantled, at Chandpal Ghat. The filtered and unfiltered water supplies have been gradually extended to the conditions which obtained in the year 1915, the former now amounting to 36,000,000 gallons per day for a population of 1,000,000 which includes the supply to small areas outside the Municipality, the latter 25,000,000 gallons per day for a population of about 850,000 persons.

The geological formation of the site of Calcutta for a depth of 25 to 30 feet is composed of loam, sand, sandy clays and clays; a peat bed of about 18 inches can be struck at varying depths of 20 to 30 feet, and subsoil water only a few feet below the surface. A boring has been made to a depth of nearly 500 feet, but no rock was met with; sand and pebbles were struck at about 200, 300 and 400 feet, and peat beds at 30 and 300 feet below the surface. The absence of marine fossils appears to shew that the strata were deposits of fresh water, and the peat beds would indicate former land surfaces.

The surface is practically flat, inclining from west to east with a slope of about 1 in 1,000. The area at present within the jurisdiction of the Municipality extends roughly north and south about 7 miles, and from the bank of the Hooghli eastward from 2 to 4½ miles. The area of the city, including the canal fringe, is 4,237 acres, and that of Fort William, Maidan Port and Added Areas, 20,547 acres, or 32 square miles. The population in 1911 of the city area, including the canal fringe, was 590,000 and that of the city and Added Areas 896,067. Males 607,674, females 288,393, houses 44,300.

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The original sewerage project for the city proper was designed by Mr. Clarke in 1857; it was commenced in 1859. Brick egg-shaped sewers were built under the main streets, stoneware pipe sewers in lanes and alleys. By 1875, 35 miles of brick and 37 miles of pipe sewers were constructed, so that commendable progress was made towards the sanitation of the city at that period. The sewers gravitated to a pumping station at Palmers Bridge, where the sewage was lifted about 10 feet to a high level sewer, by which it was conveyed about 8,000 feet to the "Salt Lake," (swamps to the east of Calcutta) drained by the Biddyadhari River. The greater part of the storm-water was discharged by storm overflows into the Circular Canal. The Local Government subsequently objected to the storm-water being any longer discharged into this canal, and in 1882 the Municipality was compelled to construct an intercepting sewer for the purpose of collecting the storm-water and discharging it to an open cut at Palmers Bridge. This open cut conveyed the storm-water from the main outfall and intercepting sewers to the Makalpotta reflux gates, through which it passed to the Biddyadhari river.

By 1884 the old project and drainage of the city proper was more or less completed, after an outlay of 95 lakhs of Rupees.

In 1888 the area of Calcutta was augmented considerably by the addition of the fringe and suburban districts generally known as the Added Areas. It then became necessary to prepare drainage projects for dealing with these extensions, and altering the city outfalls to meet future requirements.

Projects were formulated by the Municipal Engineers. Mr. Baldwin Latham was called in for his advice; he visited Calcutta and submitted reports. Amongst other matters he pointed out the serious defects in the old city system of sewers in cases where the branches join the mains "invert to invert," with the result that the free sewage flow from the branches in such cases is retarded and silt deposit takes place, which has to be removed by hand at considerable expense. His recommendation with regard to the alignment

and size of sewers for the new project was not adopted, although his advice generally was greatly appreciated. The counsel of the Municipal Engineers of the time generally prevailed with the Corporation, and the works estimated to cost about 68 lakhs of Rupees were placed in the hands of the contractors in 1897.

Through certain informalities the works were suspended under the orders of the Government in 1900. Fresh plans of the scheme were prepared and submitted to Mr. Latham again for his report in 1901. His report had the effect of causing a large part of the project not already executed to be considerably modified, and the scheme, partly in its original form, and partly as modified by the later Municipal Engineers, has been completed.

The Calcutta drainage system, old and new, of the present day containing 240 miles of sewers, is roughly represented on Plate No. 77 and briefly described in the following. Only the main collecting sewers generally of the city area are shewn, and are indicated by black lines. The whole of the city sewers gravitate to the pumping station at Palmers Bridge.

This pumping station was practically reconstructed under the new project, and two out of the three old horizontal centrifugal pumps of the original station were replaced by five compound vertical inverted jet condensing centrifugal pumping engines of about 100 I.H.P. each. The pumps with 136 revolutions per minute are each capable of lifting 2,100 cubic feet per minute through a height lift and force of 15 feet to the town high level sewer. They shew an efficiency of 63 per cent. The suctions have no foot valves; the pumps are charged by steam ejectors on the pump casings; there are no valves in the pumps except a sluice valve on the delivery worked by a hydraulic pump. During the period these pumps have been in use, *i.e.*, about twelve years, this installation, which was supplied by Messrs. James Simpson and Co., of London and Calcutta, has proved to be most suitable for pumping sewage.

Three of the pumps are capable of dealing with the maximum sewage flow of about 6,000 c.ft. per minute at present being directed

to this station, taken at 10 c. ft. per minute per 1,000 of the population of the area to be drained, 4,237 acres. The balance of power will deal with flush water and future increase. The summits of the main sewers are carried to the banks of the Hooghli, where penstocks are fixed for the purpose of periodical flushing, when the height of the tides admit, two or three days every fortnight.

There are silt pits at Palmers Bridge, and wrought iron bar screens $1\frac{1}{2}$ spaces to intercept matters that it is inadvisable to allow to pass to the sumps. The sewers are said to be capable of taking $\frac{1}{4}''$ of rainfall per hour from the area drained, and consequently discharge on the combined system. They are found to be capable of dealing with the rate of flow off of isolated rainfalls of $1\frac{1}{4}$ to $1\frac{1}{2}$ inch per hour. When the storm water overcomes the capacity of the pumps, or rises to a level above which the outfall sewers are likely to become surcharged, penstocks at Palmers Bridge are opened and the storm-water flows to a storm-water head cut and reservoir recently excavated through the Salt Lakes, $4\frac{1}{2}$ miles along and 100 to 700 feet wide, with a capacity of 52 million cubic feet, and originally capable of storing $\frac{1}{4}$ inch of rainfall per hour from the city area throughout the duration of the most inconvenient interval between tides in the Biddyadhari River, which was found by tide gauges to be $8\frac{1}{4}$ hours. Much silt has since accumulated in this reservoir. At the two outlets of the reservoir, sluices, fitted with Stoney's roller gates, have been erected to prevent the influx of river water, and admit of the contents of the reservoir being discharged through $4\frac{1}{4}$ hours of the ebb tide. The Makalpotta Sluice, which has replaced the old reflux gates, has three gates 14 feet wide by 17 feet high, and the Byntolla Sluice, five gates 15 feet wide and 19 feet high. The depth of water to which the above quantity is estimated to rise over the sills of the Byntolla Sluice on the inside is 11′-6″. The river water on the outside rises to 18·00 feet above the sill.

A new high level sewer 8 feet in diameter, capable of discharging 15,000 cubic feet per minute, has been constructed from Palmers Bridge to what is known as Point A, where, with the discharge of

the suburban system the city sewage will flow along an open V shaped concreted channel to the suburban storm water reservoir, finally discharging into the Biddyadhari River, through the suburban storm-water reservoirs and sluice. Reflux gates are erected at the head of this reservoir to prevent the sewage backing towards the city through the suburban reservoir head cut.

A project costing 44 lakhs has just been completed for the drainage of the canal area, *viz.*, between the Upper Circular Road and Circular Canal north of Sealdah station, some 432 acres. It is drained by branches, with a main sewer on the combined system, running more or less centrally through the area to Palmers Bridge pumping station. This sewer has a capacity equal to $\frac{1}{4}$ inch of rainfall per hour. At Manictolla Road a pumping station provided with two sewage and three storm-water vertical centrifugal pumps each of 7 and 21 B. H. P. respectively, driven by Crossley's suction gas engines, lifts the sewage and storm-water from a low level to a high level portion of this main sewer. Under this project some five miles of new roads have been constructed at a cost, including surplus land and construction, of some 22 lakhs.

The suburban sewerage system, carried out at a cost of some 47 lakhs, and new outfall works costing 23 lakhs of Rupees, are shewn in Plate No. 77. The main sewer No. 1, draining 2,516 acres, is capable at its outfall of discharging 8,900 cubic feet per minute equivalent to a maximum average sewage flow of 1,258 cubic feet per minute or 10 cubic feet per minute per 1,000 of the estimated future population of 125,800, taken as fifty per acre (the last census return for the area 33 plus 50 per cent. increase) with a velocity of $2\frac{1}{4}$ to $2\frac{1}{2}$ feet per second, and also 7,642 cubic feet per minute or say 3 cubic feet per minute of rainfall per acre of the area drained. The sewers of the higher district gravitate to the Budge Road steam power pumping station, where both sewage and rainfall is lifted 13 feet by three centrifugal pumps of a total of 50 B.H.P. The discharge passes along a high level service sewer to the Tolly's Nullah tidal channel, under

which it is syphoned through a 6 feet—2′-6″ steel tube, divided for storm and sewage flow laid through the bed of the nullah. The sewer then continues eastward to deliver the above quantities to the silt pits at Ballygunge pumping station.

Main sewer No. 2, which near its outfall also takes the discharge of main sewers 4 and 5, was modified after 1901, and provides for the discharge of 10 cubic feet per minute per 1,000 of the future estimated population, plus twice that quantity of rainfall—or one-third sewage, two-thirds rainfall—from an area of 1,406 acres. The velocity of the maximum future sewage flow is estimated to range between $2\frac{1}{4}$ and $2\frac{1}{2}$ feet per second in the main sewers and between $2\frac{1}{2}$ and 3 feet per second in the branch sewers. When the sewers flow full the velocity will be increased about 11 per cent. The future population was taken at the 1901 census rate for the district drained, of 60 per acre plus 50 per cent. increase, or 90 per acre, and the rainfall taken is equivalent to $\frac{3}{4}$″ of an inch per day over 1,406 acres. The full bore capacity of the sewer is estimated at 1,265 cubic feet per minute of sewage, plus 2,540 rainfall, or 3,805 cubic feet per minute, which will discharge into the silt pits at Ballygunge pumping station. The branch sewers of both mains range between 24 inches to 6 inches diameter, and at the summits (generally 9,″ 8″ or 6″ sewers) a Miller's Automatic Flushing Chamber is fixed.

The Ballygunge pumping station is provided with four Tangyes Coupled Compound Surface Condensing Centrifugal Side Section Pumping Engines, each capable of raising through a height of 18 feet, 1,760 cubic feet per minute, or through a height of 10′-6″, 3,200 cubic feet per minute. The plant has been so arranged that the maximum sewage discharge from main sewers 1 and 2 can be raised 18 feet to a height level sewer or the full discharge of these sewers in times of rainfall can be pumped on a lower lift of 10′-6″ direct into the suburban storm-water head cut, by which it will flow to the storm water reservoir, and be discharged through the suburban sluice gates to Biddyadhari River.

The high level sewer delivers the sewage at point A, where with the city sewage it continues in the combined sewage channel to the suburban storm-water reservoir, and passes out into the river through the suburban Byntolla Sluice, a sluice of 3 bays fitted with Stoney's Roller gates of similar design to those of the Byntolla town sluice.

The sewers, as will be seen above, take only a small proportion of rainfall. Provision for the disposal of storm-water from the suburbs is made by means of surface drains to discharge into the suburban head cut.

For temporarily dealing with the undeveloped, poorer and Bustee areas pail depôts, public latrines and bathing platforms connected to the sewers are provided at various points in the city and suburbs. Night-soil is collected from these areas, and conveyed in buckets and carts to the pail depôts. Other properties have either modern or the various Eastern types of sanitary fittings and are connected direct with the sewers.

Water from the streets in which sewers exist is disposed of through gullies of the usual types, and street watering is done with hose from hydrants about 100 feet apart along the footpaths, out lying district roads being served with water carts.

The author is much indebted to Mr. J. Ball Hill, A. M. Inst. C. E., for the above account.

CHAPTER XIII.

Drainage of Karachi.

KARACHI is the capital, chief port, and military headquarters of Sind, and is situated some 500 miles to the north of Bombay City. The population, according to the Census of 1901, was 166,663, the Mahomedans largely outnumbering those of any other race.

Karachi has a Municipality with an annual income of 12 lakhs of rupees.

The water-supply is derived from wells which tap the subterranean beds of the River Lyari, about 18 miles from Karachi. From this source about 2,000,000 gallons of water a day are derived. The Native city is drained on the Pneumatic System, which was designed and completed in September 1905, by Mr. James Strachan, C.I.E., then Engineer to the Municipality.

Plate 78 shews the position of the existing ejectors and sewers in full black lines and the proposed extension now carried out of the sewerage system (referred to later on) in dotted lines. The area at present sewered is about 175 acres and contains, according to the Census of 1901, a population of 27,128. The cost of the work amounted to Rs. 5,97,000, which is equivalent to Rs. 21-10-3 per head of population.

The subsoil of Karachi is of a sandy nature, largely impregnated with brackish water, for which reason all the ejectors are placed in chambers of cast iron tubbing. This tubbing is made of cast iron flanged plates, $1\frac{1}{4}$ inches thick, built up in sections. Access is obtained to the ejectors from the road by means of a circular cast iron shaft, in which a wrought iron ladder is fixed. The joints of all the tubbing plates are carefully planed and fitted together before being finally erected, to ensure their being water-tight. Strips of sheet lead are laid between the plates, which are then

screwed tight, the joints being finally caulked. This arrangement has proved satisfactory and the ejector chambers are perfectly water-tight. The ejector stations are six in number and the ejectors are fixed in pairs in each station, each being capable of discharging 200 gallons. These, as well as the tubbing, were supplied by Messrs. Hughes and Lancaster of England, whose work has stood the test of time satisfactorily. The sealed sewage and air mains were provided and laid by the same firm. The air mains were tested to maintain a pressure of 55lbs. per square inch during a period of two hours. The gravitating sewers, owing to the nature of the sub-soil, are laid partly with cast-iron pipes and partly with glazed stone ware pipes; the former being used wherever excessive water was met with in the excavation. The gradients for the pipe sewers vary from 1 in 80 to 1 in 150. The usual manholes and flush-tank arrangements have been provided, all manholes over 7 feet in depth being circular in shape and built of cement concrete rings, with the exception of five joining the ejectors, which are of cement brick-work.

Plate 79 shews the details of a concrete manhole as constructed in Karachi. The construction is well suited to a saturated sandy soil. The cement concrete was composed of 15 parts of broken stone, 10 parts of clean river sand, and 3½ parts of Portland cement. These manholes, which the Author inspected in April 1905, and which had been built nearly ten years, shewed no signs of wear and seemed in excellent condition.

At the head of each line of gravitating sewer, there is a flush tank fitted with an automatic syphon and connected by a service pipe to the nearest water main. The flush tanks are of various capacities from 200 gallons downwards.

The sewers are ventilated on Shone and Ault's System of utilizing the exhaust air of the ejectors, which is discharged up a shaft also connected with the sewer. This system is fully described in the earlier part of this book.

The air-compressing machinery was supplied by Messrs. Hughes and Lancaster and comprises two engines of about 25 Indicated

Horse-Power, each capable of compressing sufficient air to deliver 375 gallons of sewage per minute from the six ejectors. The lift, including friction, does not exceed 130 ft., and the actual working lift, exclusive of friction, does not exceed 51 feet. The two boilers are of the type known as "dryback" tubular boilers. Each boiler is capable of supplying sufficient steam at 120 lbs. per square inch pressure to work one of the air compressing engines.

The Night-soil Depots in use at Karachi consists of a paved space 50 feet square, on the centre of which the night-soil carts discharge their contents. This paved space slopes to two open chambers, in which are fixed gratings to intercept rags and stones. Each chamber is connected by a 5-inch pipe to a 6-inch pipe drain, connected in its turn with a pipe sewer. There is not much to be said for the arrangement from a sanitary point of view, as the night-soil is spread over a large area instead of discharging directly into the chambers provided for that purpose. The night-soil depots in use in Bombay, of which a plan is given earlier in this book, are much more sanitary than those at Karachi.

The whole sewage of Karachi is disposed of on a sewage farm, the location of which is shewn on Plate 68. The sewage is pumped through a 12-inch sealed sewage main to a raised masonry tank at the farm, through which it passes by gravitation to the different plots. About 500,000 gallons of sewage are discharged daily on to the 70 acres of ground at present under cultivation. The sewage is used in its crude state, and, though purely domestic, is strong and arrives at the farm in a highly putrescent condition. The soil of the farm is light and sandy, and to this must be attributed the fact that any success whate ver has attended the use of crude sewage. During the year ending 31st March 1905, the profits derived from the farm amounted to Rs. 2,019, which is extremely satisfactory; for on no other farm known to the Author has crude sewage been used continuously for a decade with any success. Most of the ordinary fodder crops are grown, such as Makai or Indian corn, Jowari, red and white, Lucerne, Hariali grass, Guinea grass, Sugarcane,

and various kinds of English vegetables. Wheat has also been grown, but with no conspicuous success. Groundnuts and cotton give great promise. It is doubtful whether, even with such a fine soil as exists on this farm, the discharge of sewage without biological treatment can be indefinitely continued.

A large number of houses in the native city are now connected to the main sewers. These connections are simple in kind and consist of 4-inch stoneware pipes on which a running syphon is fixed just outside the premises. The 4-inch house connection pipe is connected with the sewer by means of an ordinary junction pipe.

Several public latrines of a simple kind and on the water carriage system exist in parts of the city, and when seen by the Author were working satisfactorily.

In October 1901, Mr. J. Forrest Brunton, M. Inst. C.E., who succeeded Mr. J. Strachan, C.I.E., on his retirement as Chief Officer and Municipal Engineer, called the attention of the Corporation to the fact that for some time the drainage system had been giving a good deal of trouble and that there was a constant overflow of sewage from manholes, etc. The cause of this, as pointed out by Mr. Brunton, was that the sealed sewage mains were of too small a diameter, and that therefore the engines and ejectors were not used to their full capacity. In consequence of the trouble, Mr. Brunton made a series of experiments on the efficiency of the Pneumatic System, and he has recorded in his report, dated October 1901, that the average efficiency of the system at that time was 0·182, this being the average of three trials. He also reports that the efficiency of the engines and compressors worked out to 0·850. This latter result is undoubtedly good. Mr. Brunton also works out very carefully the theoretical efficiency of the system at 0·340. The difference between that and 0·182, *viz.*, 0·158, is due in his opinion to avoidable waste.

Mr. Brunton further states that the losses inevitable to this system of drainage are (1) loss due to the friction of the mechanism of engines and compressor ; (2) loss due to the unnecessary heating

of air during compression ; (3) loss due to clearance in the compressor ; (4) loss due to leakage in the air mains ; (5) loss due to leakage at ejectors ; (6) loss due to the impossibility of working air expansively in the ejectors.

Mr. Brunton concludes this interesting report by stating that the practical results were (1) that too much coal was being burnt, and that this might be remedied by substituting a Cornish or Lancashire boiler for the present type, and (2) that much more air was being used than the sewage discharge warranted.

In the spring of 1902, the Corporation decided to send Mr. Brunton to Bombay to see the Pneumatic System at work in that city and confer with the Author regarding the extension of the Karachi drainage. This proposed extension of the drainage, which has now been sanctioned by Government, is shown on Plate 68 in dotted lines. An allowance of 20 gallons of sewage per day per head of population has been taken as a basis of calculation.

For the extension of the drainage, Mr. Brunton makes four proposals, the estimates for which vary from Rs. 9,75,000 to Rs. 13,25,000. Of these four, he recommends No. 3, the estimate for which amounts to Rs. 11,20,000. The ejectors and sealed sewage mains required for this scheme are shown on Plate 78. Briefly, it provides for ejector stations, each containing two ejectors of 200 gallons capacity, except in one instance, where the ejectors are to be of 1,200 gallons each, together with sealed sewage and air mains, gravitating sewers, night-soil depôts, and engines and boilers with the necessary buildings. The extension scheme having been sanctioned, has been carried out.

In the spring of 1904, Mr. Brunton wrote a paper entitled "Notes on the working of the Shone System of Sewerage at Karachi" for the Institution of Civil Engineers. This paper deals with some recent experiments made to ascertain the efficiency of the systems. The average efficiency, based on 5 observations, was ascertained to be 0·336, but the actual working efficiency was only 0·263. This result is rather better than that obtained at Colaba in Bombay

some few years ago, where the average efficiency was shown to be 0·225.

The Author is much indebted to Dr. S. M. Kaka, D.Ph., the Health Officer and Acting Chief Officer, and to Mr. Beaumont, the Chairman of the Committee of the Karachi Municipality, for their courtesy in placing all information regarding the drainage at his disposal, and for their kind attention during his visit to Karachi in 1905.

CHAPTER XIV.

The Sewerage of Madras.

THE City of Madras is situated on a level and low-lying sandy plain on the east coast of the Bay of Bengal. It is bounded on the south by the River Adyar and on the east by the sea. The boundaries on the north and west are marked by no special physical features. The area included within the municipal boundary is approximately 27 square miles. The sub-soil consists of sand, in a strip along the sea coast, and in the remainder of the area it consists of layers of sand and clay, or sand and clay mixed. Through the sand large quantities of water percolate and at all times of the year water is encountered within a few feet of the ground surface.

In comparison with Bombay and Calcutta the history of the drainage of Madras is of recent date.

In September 1890, His Excellency the Governor of Madras appointed a Committee to consider the lines on which expenditure could be most advantageously incurred on the water supply and drainage of the city, and to furnish, if possible, plans and estimates for the same.

This Committee submitted its report in November of the same year.

As there was some difference of opinion between the Members of the Committee, it was decided that an expert should be invited to come from England and report on the scheme. In 1891 Mr. Cousins was appointed by the Secretary of State to examine and report upon the means to be adopted for improving the water supply and drainage of the City of Madras and the purification of the River Cooum. Mr. Cousins' report was communicated to the Corporation of Madras in August 1893. Colonel Pennycuick, the then Chief Engineer to the Government of Madras, generally approv-

ed of Mr. Cousins' scheme, and calculated the cost would be 61 lakhs of rupees. The Government were not then of opinion that such a large sum should be expended and recommended that the Corporation should consider whether steps should not be taken to put the existing system on a satisfactory footing.

In 1895 two separate drainage schemes were respectively submitted to the Municipal Commissioners by Messrs. Ellis & Loane. A Committee was appointed to investigate these schemes and a report was forwarded to Government in March 1896. Government approved of the scheme in February 1897, the estimate amounting in all to 32 lakhs of rupees.

By 1903 it appears that this estimate had been increased to over 48 lakhs, and the Corporation resolved to defer further work until detailed estimates for each section of the city had been prepared.

In the same year the Corporation received these detailed estimates and resolved that they "be sanctioned with the hope that the amount now provided would not be exceeded." But in November 1904 the Government addressed the President of the Corporation, asking him to state why the sanction of the Government was not obtained to the revised estimates of 48 lakhs, and requesting him to explain fully the cause of the large increase.

The President complied with the Government's request in December 1904, and in the course of his letter remarked that "it will be seen that by far the largest single cause of excess is Mr. Cousins' under-estimates of the length of sewers required."

In July 1905, the Sanitary Engineer to Government was requested to revise at a very early date, in consultation with the President and the Engineer to the Corporation, the plans and estimates for the new drainage scheme so as to make it as adequate and efficient for present and future requirements as circumstances will permit.

In September 1906, the Sanitary Engineer reported that the whole of the underground drainage work would have to be recon-

structed after re-design, and that the sections where underground drainage work has not been started should be re-designed.

Upon this the Government made an order that in view of the defects brought to light, the President is requested to call upon the Engineer to the Corporation to submit, in consultation with the Sanitary Engineer to Government, detailed plans and estimates for the scheme for the drainage of Madras for provisional scrutiny and sanction in the Public Works Department, and to re-design and reconstruct that part of the drainage system in which the works had already been nearly completed.

On this order, the Corporation in December 1906, passed a resolution to the effect that before spending any additional sums on reconstruction, more convincing evidence of the unsuitability of the present works than is afforded by the Sanitary Engineer's report is necessary, and, in the absence of such evidence, the Corporation is of opinion that the works done need not at present be disturbed. The Corporation, however, sees no objection to postpone the continuance of the drainage works.

In 1907, the Government communicated to the Corporation that if so desired they would be prepared to introduce a bill to enable the Corporation to employ a Special Engineer, the services of such a Special Engineer being retained until the new water supply and drainage schemes were completed.

In April 1907, the Corporation accepted the proposal of the Government to place its new works on drainage and water supply under an expert Special Engineer, and in December of the same year, Mr. J. W. Madeley, M.A., M. Inst., C.E., was appointed as that Special Engineer.

In April 1913, Mr. Madeley submitted to the Corporation his scheme for the complete drainage of the City of Madras. The following is a short resume of it.

At this time the existing drainage system in Madras consisted of a combination of open drains, masonry drains and pipe sewers, with five pumping stations discharging to a sewage farm. All

these drains were intended to collect and convey to the pumping stations the sullage discharged from the houses, but none of them performed their functions satisfactorily. The open drains were insanitary, the masonry drains leaky and defective, and the pumping stations were underpowered and not furnished with any means of removing the silt or floating rubbish from the incoming liquid.

Into the sewers the silt and storm-water were freely admitted through house and side drain connections, and the sewers were laid so flat that the liquid portion of the sewage did not flow sufficiently fast to carry the heavy solid matter with it, the result being that these sewers silted up and resulted in a breakdown of the drainage arrangements from the houses. The house drains were as full of faults as the sewers themselves. The five pumping stations were unprovided with silt pits and screening chambers, the pumps and engines were all inefficient, and in the case of some of a very antiquated type. The existing cast iron rising main to the sewage farm was 9 miles long. This main was intended to convey the whole of the sewage collected in the drained areas of the City, but for this purpose it was totally inadequate. It appears to have been designed to carry sewage at a maximum rate of 16 gallons per head per day for a population which existed in 1891, and what sewage this main could not take was discharged into the sea at various points.

The new rising mains are of sufficient capacity to carry 67 gallons per head per day.

The question of constructing a deep intercepting sewer running throughout the City from south to north, into which could gravitate the sewage from all the different drainage areas, was considered, but it was discarded on account of the length of time that it would take to execute, its high cost, and the considerable difficulties of its construction. Such a sewer would be wholly below subsoil water level, and the method of constructing it would be by tunnelling with the assistance of compressed air.

The alternative to this was to divide the City into a number of drainage areas, and that was adopted. The sub-soil water level lies very near the surface all through the City, and makes long and deep sewers inadvisable.

In preparing the general scheme, the areas were first roughed out to make as much use as possible of the existing sewers, and the City was divided into three main drainage areas known as the Northern, Western and Southern divisions. These divisions are practically independent of each other, and within certain limits the work of draining any one of them may be carried out without affecting the scheme of the drainage of the other two.

Each of the three main divisions is subdivided into separate drainage areas, commanded by a pumping station.

The sewage from each of the main divisions is conveyed to the farm by means of a separate channel.

The Northern division, by means of cast iron rising mains and gravitation mains of brick, stoneware pipes and cast iron pipes.

The Western division sewage is conveyed to the Grass Farm by means of pumping and gravitation mains proposed for the first time in this scheme.

The Southern division will be served by the existing cast iron main.

The total area comprised in the scheme is 15 square miles.

Plate No. 80 shows the municipal boundary and the main divisions into which the City is divided and its sub-divisions, as well as the pumping stations.

The following important principles were employed in the design of the scheme :—

(1) The closely built-up areas of the City to be drained throughout by underground sewers.

(2) Storm-water to be excluded as rigidly as possible.

(3) The silt to be excluded from the sewers as far as possible.

(4) The built-up portion of the City to be divided into areas, each area to have a pumping station.

(5) The existing drainage system to be utilised as far as practicable.

(6) Sewers to be laid at the flattest possible gradients consistent with efficiency in order to extend the boundaries of the drainage areas as much as possible.

7) The main sewers to be continued until the depth attained makes further laying impracticable.

(8) Ventilation to be provided by means of shafts and perforated manhole covers.

(9) The omitting of intercepting traps in first-class house drainage connections.

(10) Flushing arrangements to be provided at the heads of sewers.

(11) Short pump deliveries and gravitation mains to be adopted as far as possible in preference to long pumping mains.

The following rules have been followed in laying out the scheme:—

(1) The sizes of sewers to be in all cases fixed so as to be capable of carrying off in six hours half the whole daily quantity of sewage of the anticipated population in 1960 (660,000) plus an allowance for rainfall equal to one-third of the maximum flow.

(2) The sewers to run half full and the gravitation mains three-quarters full when carrying this flow.

(3) The maximum carrying capacity of the pipe sewers will be $5\frac{1}{3}$rd, the estimated average dry weather flow of 1960; the brick gravitation mains $3\frac{1}{2}$ times the same dry weather flow.

(4) The mean dry weather flow from the sewers is taken at 25 gallons per head per day on the anticipated population of 1960.

(5) The sewers to be laid at gradients which will give self-cleansing velocities.

(6) For reasons of economy brick sewers should be as far as possible used for sewers that are too large for the employment of stoneware pipes.

(7) The main brick sewers to be of circular section.

(8) Cast iron pipes to be laid as sewers in deep excavation where especially large volumes of water are encountered.

(9) Rider sewers to be employed wherever economy, safety or convenience can be secured by their use.

(10) All manholes to be provided with cast iron covers and never to be more than 300 feet apart.

(11) Special types of flush-out and dry latrines have been designed suitable for use by the different classes of the community.

(12) Night-soil depôts to be provided for the introduction of night-soil into the sewers at suitable points.

(13) At the pumping stations the plant to be sub-divided so as to be capable of dealing economically with the usual variations of flow. Stand-bye plant to be provided.

The pumping plant, exclusive of the stand-bye to be capable of dealing with three times the estimated average dry weather flow of 1936.

(14) Where there is considerable head, or where the head varies greatly, direct acting Steam Engine Pumps to be employed. Centrifugal Pumps driven by Oil Engines, Suction Gas Engines or Electric Motors or Pneumatic Ejectors or Humphrey Pumps to be employed where the lift is low and where the head is constant.

(15) All sewage arriving at the stations to be screened and deprived of silt before it reaches the pumps, by special silt pits and screening chambers.

(16) House drainage to be so carried out as to prevent the introduction into municipal sewers of silt and storm-water.

The population of Madras in 1911 was 518,660, and the scheme provided for a prospective population in 1961 of 660,000.

For the most part it is proposed to construct new sewers throughout the city, and to take up many of the existing sewers in areas already sewered notably with concrete pipes.

The ventilation of the sewers is to be by columns placed in carefully considered positions, 6″ in diameter and from 20·-0″ to 30·-0″ high, with certain open grated manhole covers to act as inlets.

The question of utilising the existing pumping stations was very carefully considered and the conclusion arrived at in every case was that it was better to erect a new pumping station than to try and modify the existing station.

The following is the list of new pumping stations proposed and the table gives the maximum flow, type of engine and the total H. P. required and the efficiency expected :—

Name of Station.	Maximum quantity to be lifted in gallons per minute.	Type of plant proposed.	Total B.H.P. to be provided.	Approximate pump efficiency expected.
South Mylapore ..	775	Oil Engines and Centrifugal Pumps.	15	45%
North Mylapore ..	1,225	Steam-driven Plunger Pumps.	100	75%
Edward Elliotts Road.	540	Electrically driven Compressor and Ejector or Oil Engines and Centrifugal Pumps.	11	40%
Ice House Road ..	2,738	Steam-driven Plunger Pumps.	150	80%
Napier Park ..	7,560	Do. ..	290	85%
Greame's Road ..	814	Oil Engines and Centrifugal Pumps.	15	45%
Lang's Gardens ..	2,039	Do. ..	26	50%
Purasawakkum ..	6,980	Do. ..	150	60%

Each pumping station will be provided with a collecting well into which the sewers will deliver. From the collecting well the sewage will flow through silt pits and screening chambers in dupli-

cate. From the screening chambers the sewage will flow to three or more pump suction wells, one for every pump, each 6 feet in diameter.

For sewers up to 21″ in diameter stoneware pipes will, as a rule, be employed, except in a few cases where bad ground and large volumes of water render it desirable to use cast iron pipes. For sewers above 21″ brickwork will in most cases be resorted to.

The reason why brick sewers will be used wherever practicable is that they are much cheaper in Madras than cast iron pipes for all sizes above 24″. Storm-water overflows will be provided where-ever practicable, and every pumping station will be provided with an overflow. There are at present a number of overflows into the Madras Harbour, which will be utilised.

To deal with the larger quantity of sewage which may be expected from the new water supply, and after a complete system of sewers has been laid, it is proposed that the existing sewage farm should be extended northwards and for this purpose a new channel 9,800 feet in length will be constructed, and at every 450 feet along its length valves provided through which the sewage may be turned into the distribution mains, consisting of 15″ stoneware pipes, laid underground in parallel lines at right angles to the sea, and every 200 feet along these mains will be constructed valve chambers from which the sewage can be turned into open channels running at right angles to the distribution mains. The open channels will be lined with 15″ stoneware channels, and slightly raised above ground surface to allow the overflowing liquid to flow over the ground.

The principle of the proposed irrigation system is very similar to that which has already been installed in the sewage farm and has proved quite satisfactory.

In the future, when the sewage system is more complete and all the solids are taken into the sewers, it may be necessary to deal with the sewage before turning it on to the land. To meet this possibility, designs for septic tanks have been prepared in which

the sewage may be treated and the sludge removed, so that the effluent will contain a comparatively small amount of solid matter. The total area of these tanks is 206,400 square feet.

It has been very difficult to calculate the present output of sewage, owing to leaky drains, inferior pumping plant, and the inclusion of storm-water, but in 1940 it is estimated that $34\frac{1}{4}$ million gallons will be pumped and in 1961 $40\frac{1}{4}$ million gallons.

The estimated cost of these works amounts to Rs. 98,26,400 and includes the cost of all works included in this report. If septic tanks are required at the sewage farm, Rs. 2,19,500 must be added, making the total cost of the scheme Rs. 1,00,45,900 (£670,000).

It is assumed that the night-soil depôts and latrines will be paid for out of revenue, and they are not included in the estimates. The Harbour overflows are also to be debited to the Port Trustees.

The estimates assume that all house connections will be done at the expense of the owners.

In all existing houses the Corporation will lay free of cost the street connection to the intercepting trap or silt catcher.

The surface water drainage of Madras is not nearly so important as in some cities. There is an annual rainfall of about 40 inches, which practically all falls in four months, and owing to the fact that the rainfall, which does not soak into the ground, passes away slowly down natural drainage channels, artificial ditches and old masonry drains to the sea, only some inconvenience is caused and very little harm is done. The existing masonry sewage drains not longer required for sewage will be linked up with side drains and utilised for surface water.

For the above information the author is much indebted to Mr. J. W. Madeley, M.A., M. Inst. C.E., who has kindly allowed notes to be taken from his report to the Corporation of Madras, dated the 10th April 1913.

CHAPTER XV.

Sewerage of Benares, Lucknow, Mirzapur and Lahore.

In February 1906, the author visited the Sewerage Works of Benares, Lucknow and Mirzapur in company with Mr. Lane Brown, M. Inst. C.E., M.I.M.E., the then Supervising Engineer.

All these works were in progress, those at Lucknow and Mirzapur possessing peculiar interest, in that an open system was being applied to both cities. The short description given below will suffice to shew how well-suited this system is to Eastern cities or towns with only a small water supply. When an urban water supply does not exceed 10 to 12 gallons per head of population sewerage as adopted at Lucknow and Mirzapur is undoubtedly the best. The author was much impressed with it, as well as with the excellence of the work carried out by Mr. Lane Brown, by whom the works were being done departmentally, subject to the scrutiny and approval of the Sanitary Engineer to Government, Mr. D. W. Aikman. The economy thus secured, as against contract agency, is very considerable, and the Government has been so favourably impressed with it that they have agreed to a similar procedure for Fyzabad, Allahabad and Muttra, as also for many of the small municipalities of the United Provinces.

Benares.—Benares is the holiest city of the Hindoos, and is situated on the Northern bank of the Ganges, with a population of between 200,000 and 300,000, of whom nearly 60,000 represent a floating population of pilgrims. The water supply is 4½ million gallons per diem and the rainfall averages above 40 inches per annum.

The first complete scheme for the drainage of this city was designed in 1889 by Mr. A. J. Hughes, M. Inst. C.E., the then Super-

vising Engineer for Municipal Water Works, North-West Provinces and Oudh. The scheme was on the combined system, that is to say, storm-water and sewage were both to be removed in the same sewer. Mr. Hughes' scheme provided very good gradients for the sewers and two pumping stations, through which it was proposed to lift the sewage twice. The main outfall for the whole system was to be constructed on the River Ganges, half a mile below the city, and the discharge was to be into 40 feet of water when the river was at its lowest. The cost was estimated at Rs. 19,12,208 and the working expenses at Rs. 36,768 per annum.

At the end of 1890, Mr. Baldwin Latham, M. Inst. C.E., was invited to visit India to advise the Municipalities of Bombay and Calcutta regarding their drainage problems, and advantage was taken of his presence to obtain his advice on the proposed scheme for the drainage of Benares. The report which he submitted in February, 1890, shewed that provision should be made for a population of not less than 300,000 people. He approved generally of Mr. Hughes' scheme, but recommended that no pumping should be undertaken, and that the scheme should be based entirely upon gravitation. This necessitated a certain reduction of the velocities which Mr. Hughes had contemplated, and provided a velocity of three feet per second with sewers running half full. Mr. Latham took the ordinary dry weather flow at 4 cubic feet per head per day which gave roughly a mean flow of 700 cubic feet per minute. He agreed with Mr. Hughes that though it was generally desirable to exclude the rainfall from sewers, in this particular it was better to combine the rainfall with the sewage. In the present project, however, provision has been made for the exclusion of stormwater.

As to the disposal of sewage, he recommended its discharge direct into the Ganges, without any kind of treatment, and rightly pointed out that the great dilution which would immediately occur would destroy all germs of disease.

Mr. Baldwin Latham's recommendations reduced Mr. Hughes' estimate by Rs. 2,11,642.

In 1898 Mr. Lane Brown, who succeeded Mr. A. R. Wilson, M. Inst. C.E., as Resident Engineer, took charge of the work, and has carried out the present scheme.

In 1899-1900, financial reasons obliged Government to revise Mr. Latham's scheme, and to reduce the estimate to Rs. 14,00,000. The whole of this scheme has now been carried to completion departmentally, and a project has been prepared for the completion of the remaining portions at a cost of Rs. 20,00,000.

Many of the sewers are laid at a great depth, in lanes, which do not average more than six feet in width, with overhanging houses of from four to six stories on each side. In spite of great difficulties, these sewers were most successfully laid. Benares, for many years, possessed an old system of obsolete drains which had their outfall at various points on the Ganges, and these passed through the narrow lanes. It was necessary in constructing the new sewers to arrange for the carriage of the sewage whilst the old sewers were being demolished and removed, until the new sewers were complete. The greatest care had to be expended upon this task, in view of the caste prejudice of the workmen engaged, and also in view of the probability of the collapse of houses which were built mostly on uncertain foundations. It is to the credit of the Engineer that the whole work was carried out without damage or demand for compensation of any sort.

Pending the erection of ventilating shafts, for which arrangements have on account of local prejudice, to be slowly made, ventilating manhole covers provide the only means of ventilation.

Automatic flushing tanks are provided at the heads of all sewers.

Plate No. 81 is a drawing of a water carriage system latrine, which has been introduced into the United Provinces by Mr. Lane Brown. Some thirty of these latrines have been erected and many have been in use for five or more years, having given great satisfaction. They provide fully for the wants of the poorer classes and are in popular favour. Some of the largest have 96 seats, and are used by 4,000 people daily. The author carefully examined

some of these latrines and found them free from any nuisance. Attached to each latrine is a pail depôt of simple and economical construction, which works well.

Benares is, with the exception of Cawnpore, the only City in the Province which is, or is likely to be, sewered. Most of the other towns are, or will eventually be, drained on the open system, which, where practicable, is the best suited to the needs and uses of the people.

The details of the Cawnpore sewerage system have been based on the experience gained in the Benares works.

LUCKNOW.—Lucknow is the capital City of the Province of Oudh, and is included in the United Provinces. It is situated on both banks of the River Gumti, which is a tributary of the Ganges.

It ranks fourth in size among Indian cities, and has a population of nearly 300,000. The water supply of the city is 2,000,000 gallons per day, or about 10 gallons per head, and is derived partly from wells, but principally from the River Gumti, from which it is pumped and then filtered.

The sullage of the whole city is removed by means of open surface drains, which also carry off the surface water in the monsoon. The annual rainfall average 40 inches, and the surface drains are calculated to deal with a flow of 2 inches per hour per acre. Provision has been made for the sullage water to be wholly carried in a new system of open drains, and free use has been made of certain old drains which are connected with nullahs discharging into the river as storm overflows.

Covered drains have been constructed, with which open surface drains have been connected. In no instance do the surface drains run to any great depth.

For drainage purposes, the city has been divided into seven districts, each with its outfall into the Gumti. To obviate the disadvantage of having open drains of great depth, the streets have been raised or lowered according to requirements.

Plate No. 82 gives the details of the cross-section of these open drains. They are calculated for the size of the district they have to serve. Though not shewn in the Plate, the invert is in all cases constructed of lime and cement concrete moulded at a central store, and the working face of the invert is of neat Portland cement. The result is excellent and sanitary. No night-soil is admitted into these drains, but is removed by hand and trenched outside the city. Under the scheme, however, the Benares type latrines and pail depôts will serve the whole city, each having its separate system of purification, and the effluent only will be allowed to enter the surface drainage.

The total estimate for the sewerage of Lucknow is Rs. 20,00,000. The Cantonments are not included in the above scheme.

At each of the seven outfalls, the surface drains will discharge into Liquefying Tanks, from which the effluent will pass on to a continuous filter, provided with a Fiddian Distributor.

The above system of drainage for small Indian cities if well conserved, would appear to serve every sanitary requirement. In the smaller lateral drains, a 'bhisti,' in conjunction with a sweeper, can deal with 3,000 feet of open drain, both morning and evening, and keep both the drains and paved lanes in a sanitary condition. For the larger laterals and mains, flushing tanks are necessary.

MIRZAPUR.—Mirzapur is situated on the south bank of the Ganges, some 60 miles below Allahabad. The population is about 60,000, and the rainfall averages 40 inches per annum. The present water supply is derived from wells and the River Ganges, and is calculated to be equal to about 3 gallons per head per diem, but a new project, on a basis of 12 gallons per head, and estimated to cost Rs. 5,00,000, is under consideration.

The city lies for the most part on the banks of the river, and, as is often the case with riparian cities in India, the land falls back from the banks. The drainage has, therefore, to be carried out against the lie of the land, necessitating deep excavations in places.

From time immemorial, Mirzapur has contained old masonry drains, which, though large and well constructed, are of obsolete shape.

The scheme is carried out on the same lines as previously described in the case of Lucknow, and the design of open drains is as shewn in Plate 82. Streets have been raised or lowered according to the requirements of the gradients of the drains.

It has been found necessary to cover some of the open drains for short distances with stone slabs, with suitable manholes, since the configuration of the land necessitated their being laid at a considerable depth.

Five outfalls into the Ganges are proposed for the discharge of the sullage, and the purification will be on the same principles as at Lucknow.

All excreta is removed by hand and trenched outside the town, none being admitted into the drains, but the scheme embodies the same provision of latrines, pail depôts and separate purification as at Lucknow.

The sewerage works are estimated to cost Rs. 2,25,000.

LAHORE.—Through the courtesy of Messrs. Lane Brown & Hewlett, Consulting Engineers at Lucknow, the author is enabled to give a short description of a scheme recently approved by the Municipality and the Sanitary Engineer to the Punjab Government for the drainage of Lahore.

In the Autumn of 1914, Messrs. Lane Brown & Hewlett were entrusted with the preparation of a scheme of sewerage for the Lahore city and the Civil station.

In May 1915, it was resolved that the preliminary report on the scheme be approved, and that Messrs. Lane Brown & Hewlett be asked to prepare the final scheme subject to certain modifications.

At a later date a full scheme was presented with an estimate amounting to a sum of Rs. 46,45,146.

The city of Lahore is situated about 2 miles from the southern bank of the Ravi River, with a Civil station area lying to the south

of the city proper. The present population of the city, including the Anarkali Bazar, amounts to 135,860. The city has an area of 716 acres (140 per acre) and includes the population of the Civil lines of 119,449 with an area of 3,607 acres (32 per acre).

The existing drainage consists of a system of open brick surface drains supplemented in various parts of the city by brick sewers which take the discharge from the open brick drains.

The outfalls from the city are intercepted by an open brick drain which runs on both sides of the city to an outfall into a brick sewer which carries the sullage some three-quarters of a mile to cultivated lands, where the main portion of it is lifted by Persian wheels and utilised for the irrigation of crops.

These brick drains are of faulty description, with rough surfaces, and are generally constructed with irregular gradients, having wide joints through which the sullage percolates into the subsoil, leaving behind in the drains a deposit of filth which, when dried by the sun, is converted into dust of a most injurious character, and is distributed by the winds among the adjacent roads and buildings, where it is breathed by the inhabitants and, what is more likely, contaminates such food as is open to the air in the bazaars and shops.

The water supply of Lahore is inadequate, and proposals are now in course of preparation to increase it, and a sufficient supply will shortly be available to insure rapid water carriage of the sewage through the proposed new sewers.

The drainage of the city and Civil lines falls naturally into two divisions :—

(*a*) That of the city and part of Anarkali Bazaar.

(*b*) The whole of the Civil lines, Railway quarters and the remaiing portion of the Anarkali Bazaar, Gwalmunds Kila, Gujar Singh and Mozang.

The present population of the city, as before stated, amounts to 135,860, and the proposals for drainage are based on a calculated dry weather flow of 2 gallons per head per hour.

The position of the outfall is well beyond the inhabited area, and the sewers have been designed to remove the above amount of dry weather flow, plus $\frac{1}{4}''$ of rainfall per hour, which is found to be the first off flow.

The levels of the city area admit of the whole of the sewage discharge being intercepted by two sewers, one to the north of the city and the other to the south. These two sewers will join at the Bhati Gate into one main sewer, which will continue to the lands at present under sewage irrigation on the bank of the Ravi, the area of which is ample enough to receive the increased amount of sewage proposed to be brought down by the new system of sewers.

The northern intercepting sewer has its summit at Kashmir Gate, and passes in a westerly direction to the Masti Gate, and then south of the Fort passing along the Hira Mandi, Taksali Gate, from whence it takes a turn to the south and discharges at the Bhati Gate into the main sewer.

The southern intercepting sewer has its summit at the Khijri Gate, and passes westward to the Ikki Gate, and then turns south along the east corner of the city and, passing along the Delhi and Akbari Gates, it turns west, intercepting en route the branch sewers at Mochi, Shah Alimi, Lohari, Mori and Bhati Gates, and finally discharges into the main sewer.

Throughout all the main streets and the vehicular traffic lanes, provision has been made for branch sewers, which are either brick sewers or pipe lines, according to the population in the district, and all these sewers are capable of carrying the $\frac{1}{4}''$ per hour in addition to the dry weather flow.

Provision has also been made for kerb and channel drains, with stone guard sets in all the vehicular traffic roads or lanes with gulley pits at necessary intervals. These pits are connected to the sewers by disconnecting trap blocks, which will prevent any discharge of sewer gas or air.

Latrines and pail depôts for the rapid disposal of night-soil have been provided on sites convenient to the sewers. Flushing tanks

have been provided at such heads of sewers where the flow does not allow of self-cleansing velocities.

As there are one or two places in the city which suffer from flooding during periods of heavy rainfall, provision has been made at these points for discharging the storm-water into the existing main storm-water drain outside the walls of the city.

As previously stated, the present arrangement for disposing of the sullage is by means of Persian wheels to cultivators for irrigation purposes. It is proposed to discontinue their use, and to instal in lieu of them a pumpig station on the main sewer at an outfall capable of dealing with a maximum normal flow of 2 gallons per head per hour. The pumping plant will be in duplicate, and will deliver the sewage to the cultivators at a sufficiently high level to enable them to irrigate their fields by gravitation.

In time of storm the $\frac{1}{4}''$ rainfall per hour will be taken through a new outfall sewer and discharged directly to the nalla which flows into the River Ravi. The great flow of the river in times of rain, as compared with the quantity of dilute sewage, will prevent any nuisance arising.

Any storm-water in excess of the $\frac{1}{4}''$ per hour will discharge by means of flap valves into the existing storm-water drains and in this case also the dilution is so large as to prevent nuisance.

The Civil lines area contains the Anarkali Kila, Gujar Singh and Mozang Bazaars. These areas are heavily populated and will be dealt with on the same lines as those described for the city area. The remaining portion of the civil lines is sparsely populated, and several areas are at present unpopulated, but will probably at some future period be built over.

The present population, including the Bazaars, as before stated is 119,449. Allowing for a future population, when the open spaces are built over, of 25 persons per acre, which is the average of the present population on built areas, it is necessary to provide for a population of 134,825 persons.

The whole of this area is to be dealt with by means of one main sewer, starting from near the Railway bridge and continuing through Gwalmandi and passing along the Beadon Road, where it picks up the sullage and sewage from the surrounding bungalows, besides intercepting the sullage of the Railway quarters area, Kila Gujar Singh area, Government House area, etc.

At this point it will be necessary to raise the sewage to a high level sewer, and for this purpose a pumping station is proposed. The high level sewer passes along Temple Road to the junction of Multan Road, where it meets the Southern Anarkati Branch sewer, and then gravitates to Chanbargi, where it divides, and the normal flow is taken off by means of an ovoid brick sewer to a pumping station to be constructed half a mile beyond the existing pumping station, which is to be done away with because of the close proximity of quarters being now built for Government clerks.

The storm-water is discharged into an existing storm-water channel,and anything in excess of this will flow into existing storm-water channels situated in the Bazaar areas. The dry weather flow will be lifted at the pumping station and distributed to the cultivators.

Messrs. Lane Brown & Hewlett explain that it is more economical to provide an intermediate pumping station on the main sewer in the civil lines than to construct a long deep gravitating sewer. The difficulties of the construction of such a sewer are that the lower portion of it would be 5 to 7 feet below subsoil water level and it is doubtful if the recurring charges on an intermediate pumping station would be more than the interest on the extra cost involved in a deep sewer.

There are three small low-lying areas, *viz.*, the Government House area and Garhai area, the Financial Commissioners' Court area, and the Jail area, which cannot gravitate to the main system and one such area, the Veterinary College in the city area, which also cannot be served by gravitation. For the drainage of these areas it will therefore be necessary to install small pumping stations.

The outfalls from the city and civil lines area are about a mile apart, but they both discharge on to the disposal area and the southern bank of the Ravi.

The point of discharge in each case will be sufficiently high to allow of distribution by carriers to all parts of the cultivated areas.

The amount of this area reserved for cultivation purposes is 1,495 acres, which will be ample for the present and prospective discharges.

Attached to the report is an interesting statement of comparative cost at Lahore of various methods of pumping, *viz.*, centrifugal pumps driven by electrical motors, compressed air actuated by steam power, compressed air actuated by electric motors and centrifugal pumps driven by oil engines.

It appears that it is possible to obtain electric current at 1·25 annas per unit, and Messrs. Lane Brown & Hewlett explain that this rate may possibly be reduced to 1 anna per unit.

The cost of the different plants works out as follows :—

Electricity	Rs.	55,755
Compressed air and steam	,,	9,10,591
Compressed air and electricity	,,	6,56,392
Oil Engines	,,	51,700

The advantages are in favour of electricity, there being no cost incurred for the erection of machinery as is the case with compressed air and oil engines.

CHAPTER XVI.

Drainage of Rangoon.

Rangoon is remarkable for having been the first city in the East to adopt the Pneumatic Ejector System patented by Mr. Isaac Shone.

It is the capital of Burma, and had, in 1889, when this system of sewerage was projected, a population of 240,000. The population has since that year greatly increased, and the system of drainage then carried out has proved to be too restricted, and has been largely added to, both in ejectors, sewage and air mains.

Previous to 1784, no attempt had been made to deal with the drainage of the city. Cesspools were everywhere allowed, and the well water, then the only water available, very soon became fearfully polluted as the sub-soil of the city was more and more impregnated with sewage.

The sewerage of the City on the Pneumatic System was sanctioned in 1887, work commenced early in 1888, and completed in 1890.

From this date gradually cesspools were abolished as the houses were connected to the system.

Simultaneously with the opening of the drainage scheme a good water supply, consisting of 40 gallons per head of population per diem, was provided from what is known as the Hlwaga Water Scheme. The drainage scheme was designed conjointly by the then Municipal Engineer, Mr. Clark, and Messrs. Shone and Ault of Westminster.

Plate 83 shows the sewage mains, air mains, gravitating sewers, ejector stations and flushing tanks as now existing.

The Author is indebted for the following notes to Mr. L. P. Marshall, M.Inst. C.E., Chief Engineer to the Rangoon Municipality:—

In the original scheme the part of Rangoon dealt with was

divided up into 22 blocks and between every two lines of houses, except in two blocks, there is a space of 15 ft. left for drainage purposes.

In these drainage spaces 6″ C. I. gravitating sewers are laid. Each block is provided with a Shone's automatic ejector into which the sewage flows by gravitation.

The ejectors, which are in duplicate, having a capacity of 200 gallons each, are fixed in cast iron tubing at levels below the ground to suit the levels of the block from which they receive the sewage, and these ejectors, when full, automatically discharge the sewage into sealed sewage mains. The sewage is ejected by compressed air, which is supplied from the air compressing station through cast iron pipes which are connected to the ejectors by automatic valves. The works were commenced in February 1888 and part was put in operation in August 1889, now 26½ years ago, and finished in 1890. The approximate cost of the scheme was £173,333 to £186,666. The system comprises three sets of 150 I. H. P. steam engines and air compressors, five Lancashire boilers each stated to be 75 I. H. P.

Six miles of sealed sewage C. I. mains ranging from 21 inches to 6 inches in dia.

Twenty-two miles of 6″ C. I. gravitating mains.

5 miles of C.I. air mains ranging from 3 inches to 10 inches in dia.

44-200 gallons capacity Shone's Ejectors in 22 Ejector Stations.

The crude sewage all being discharged through the 21″ dia. main near Monkey Point into the Rangoon River.

In 1904 the late Mr. Edwin Ault was brought to Rangoon by the Municipality in consequence of the unsatisfactory manner in which the Shone system was working, to advise the Municipality, and the following is extracted from his report.

"The problem to-day as regards the quantity of sewage to be expected from the area of the Rangoon town proper is a vastly different one compared with what it appeared when the original project for the sewerage of the town was submitted in 1885 and

carried out in 1887-90. The total population of the area to which the original sewage project applied in the census of 1901 is shown to be 87,532, which is more than double that anticipated by the Municipal Engineer in 1885."

It is interesting to note that, an account being made of the population in Block E-3 in 1904, it was found to be 6,241, which gives a population of 315 persons per acre, an increase of 59·1% on the density of this block in 1901 in 3½ years.

The above shews that liberal ideas of what will be required from sewage works in the near future must be entertained. From tests made at one Ejector Station it was found that the ratio of the maximum to the mean flow of sewage worked out at 1·2 taken on a 15 minutes' maximum flow, therefore the ejectors should be designed to deal with double the mean flow for the day. And from the engine and compressor revolution records, Mr. Ault came to the conclusion that the general system must be capable of dealing with a maximum flow of 1½ times the mean flow.

In Block E-3 the flow of sewage was found to be 41 gallons per head of population.

In re-designing the system, Mr. Ault took the following data :—

The town proper comprises an equivalent of 40 full-sized blocks and allowing for a population of 6,000 people per block with a sewage flow therefrom of 40 gallons per head, this gives a population of 240,000 and a maximum flow of sewage, taking it at 1·5 the mean=10,000 gallons per minute.

Working on the above figures it is shewn that it was necessary to provide a 36 inch dia. discharge main in addition to the 21″ main laid in 1887-90.

The quantity of free air at 30 lbs. pressure required to deal with 10,000 gallons per minute is 5,360 cubic feet per minute.

The compressor plant at that time consisted of the 3 origina compressors first installed and two extra compressors put in at a later date.

The three old engines were in such a bad state that the Municipality was advised to discard them altogether and to install new ones of greater air capacity and of more economical design.

This has since been done and two new compressors have been installed and to-day the installation consists of—

Two small air compressors each of a capacity of 1,100 c. ft. of free air per minute at 100 revolutions.

Two new large air compressors of a capacity of 5,500 c. ft. of free air per minute.

Five old Lancashire boilers 22 ft. × 6′-6″ dia. and one new Stirling boiler with an under-feed stoker and a new chimney.

The Stirling boiler has a working pressure of 150 lbs. per square inch, a heating surface of 2,861 super feet, a grate area of 59¼ ft. and is capable of evaporating 10,600 to 13,000 pounds of water per hour from and at 212° F. and a Stirling Integral Steam Superheater which will heat the steam produced by the boiler when working from 100° F. to 120° F.

The steel self-supporting chimney is 4′-0″ dia., 80 ft. high and constructed of plates ranging from ⅜ to ¼ inch thick and is lined with firebricks for a height of 50 feet.

The Horizontal High Speed Triple Expansion Condensing Steam Air Compressors are as follows :—

H. P. Steam Cylinder	..	=	15	inches dia.
Intermediate Pressure	..	=	23½	,, ,,
Low Pressure Cylinder	..	=	37	,, ,,
The three Air Cylinders	..	=	24	,, ,,

The stroke of all is 24 inches and they are capable of compressing 4,200 c. ft. of free air per minute to 30 lbs. per square inch above atmosphere at 112 revolutions per minute and running up to a piston speed of 600 ft. per minute or 150 revolutions in cases of urgency.

In 1913 Mr. Marshall estimated that sewage from a population of 110,000 was being dealt with and allowing 50 gallons per head of population and that the maximum flow would be twice the mean

of the 24 hours per minute, therefore 7,639 gallons of sewage must be dealt with which requires 4,100 c.ft. of free air compressed per minute from 28 to 30 lbs. pressure per square inch. One of the large engines could do this working at 112 revolutions per minute.

In 1921 he estimates that probably the sewage from a population of 165,000 will have to be dealt with and 6,143 c. ft. of free air compressed. This will necessitate one large engine and one small engine working together.

With the addition of the Stirling boiler it will be possible to maintain an Indicated Horse Power of 800 against present requirements of 570 so that there is ample power provided so far as can be seen for many years to come.

It will be seen from plan No. 83 that there are now 35 Ejector Stations.

The cost of the new work amounted to £131,071.

CHAPTER XVII.

Drainage of the City of Singapore.

SINGAPORE is the principal commercial centre in the Straits Settlement and has a separate Colonial Government. It consists of an island, 27 miles long by about 14 miles broad, lying at the south end of the Malay Peninsula. Situated within 1° of the Equator, it possesses a very temperate climate, the annual range of temperature being between 70° and 90° Fahrenheit. The annual rainfall averages 92 inches. Singapore City has largely increased in size and importance of late years, and now boasts of a population of 228,554.

Until recently it had no regular system of sewers. The whole of the sullage from baths and kitchens was conveyed by open roadside drains, constructed along the sides of the streets, which ultimately discharged into the Singapore river or the sea at various convenient points. These drains were cleansed and swept twice a day by Municipal coolies.

The City is for the most part flat, and the lower portions are occasionally submerged by extraordinarily high spring tides.

There are a number of public latrines on the dry system in the City, and the contents of the pails and pans were conveyed to cocoanut plantations beyond Municipal limits. All excreta from houses was similarly removed by Chinese coolies to vegetable gardens outside Muncipal limits.

In 1893 the late Municipal Engineer, Mr. J. MacRitchie, M.Inst. C.E., submitted to the Municipal Commissioners a scheme for the removal and disposal of all the excreta. In his report he pointed out how dangerous the existing system was, and how completely the city lay at the mercy of a set of men, who might at

any moment strike work. He also said that a complete system of sewerage for the city would, on account of its natural configuration, and the soft nature of the soil, be attended with very great cost, both in the construction of the sewers and the maintenance of powerful pumping engines necessary to raise the sewage to a sufficient level to discharge it by gravitation into the sea. Mr. MacRitchie's proposals were to collect the excreta and convert it into poudrette, as he was of opinion that the material would command a ready sale among planters and others. The Commissioners therefore decided to instal a small poudrette plant at the Tanjong Pagar Reclamation, which was completed and started in 1898. This installation was discontinued in 1904 on account of its excessive cost, the difficulty of the sale of the poudrette, and the complaints o nuisance.

Early in 1904, the Municipal Engineer, Mr. R. Peirce, M. Inst. C.E., submitted a report to the Commissioners in which he laid down that the discharge of night-soil into the sea was the most satisfactory way of dealing with the problem. He recommended the main channel on the south side of St. John's Island as the most suitable position for that discharge, the currents at this place being east and west.

His scheme was to divide the City into districts and to instal in each district a Shone's pneumatic ejector, which would receive the excreta and discharge it into a sealed sewage main, varying in size from 3 inches to 8 inches at the final landing jetty, whence it would be discharged into barges and from them shot into the sea. He proposed that all the latrines in the City should be furnished with pails of one pattern, supplied and maintained by the Commissioners, these pails to be 12 inches deep by 1 foot 3 inches in diameter, and closed with a lid made air-tight by a rubber joint secured to the pail by a spring. Each of the five districts would contain 3,000 houses, and the pails would be changed once in 2 days. This would mean the removal of 1,500 pails to each receiving ejector every day. The pails would be taken away in vans and clean pails

would take the place of those removed from latrines. The estimated quantity of excreta to be dealt with at each receiving ejector would be 4,050 gallons or 18 tons per day. The total cost of the proposed scheme, exclusive of the cost of pails, was estimated at $ 580,710, and the annual working expenses at $ 239·008.

It was not proposed to make any alteration in the existing road-side open drain system for the disposal of sullage.

Mr. Peirce's report was approved by the Commissioners, but action was delayed because in 1906 H.E. Sir John Anderson, the Governor of the Straits Settlement and High Commissioner of the Federated Malay States, requested Professor W.J. Simpson, M.D., F.R.C.P., to fully report on the sanitary condition of the City. His report was issued in February 1907, and described in great detail, the insanitary and unsatisfactory state of affairs. This was followed by a report of the health and disposal of sewage Committee, dated 6th of March 1909, and in the autumn of that year Mr. G. Midgley Taylor, M. Inst. C.E., F.C.S., of the firm of Messrs. John Taylor & Son, Westminster, was invited to visit Singapore and advise on the best means of dealing with the sewage of the City.

Mr. Midgley Taylor spent November and December in Singapore, and reported in July 1910. He generally agreed with what Dr. Simpson had stated, as to the insanitary state of the city, and fully appreciated the urgent need for drastic measures. He stated that the present methods of dealing with and disposing of the noxious matters created by the population were extremely crude, and said. ' There is no system of underground drainage, the rainwater, together with sullage water and soiled filth from the dwelling houses, is allowed to discharge into open channels formed along the sides of the road, and these channels convey the liquid in its crude state into the nearest body of water available. The night-soil is separately collected, partly by the Municipality, but chiefly by private contract, and is dealt with in various ways."

Mr. Midgley Taylor, after full consideration, stated that the objectives to be aimed at were, the devising of an entirely new system of drainage and recommended the following :—

(*a*) The entire exclusion from the open street drains, of all foul matter and liquid.

(*b*) The institution of water-closets throughout the City.

(*c*) The connection of each separate property to an underground sewer by means of a closed drain provided with an interceptor trap at the back of each property.

(*d*) The conveyance as rapidly as possible of the whole of the sewage to some point of outfall or place of disposal.

He pointed out that all these proposals were not possible of immediate attainment, because over the larger part of the city, buildings had been extended until they were back to back, and there were no vacant areas available for drainage purposes, therefore all drainage had to be taken through the front of the properties which was a most undesirable arrangement, and he recommended the formation of back lanes.

Mr. Midgley Taylor was of opinion that the Municipal Engineers' proposals in his report of February 1904, dealt only with one part of the nuisance, *viz.*, the night-soil, and left untouched the collection and disposal of sullage water and other filth at present passing down the side channels and the consequent fouling of the foreshore of the river or sea, and he proposed the construction of a through system of underground sewers to which the sullage water and filth flowing along the open gutters would be led, and that public latrines directly connected with the sewers should be built at convenient points in the Native and Chinese quarters.

Mr. Midgley Taylor did not agree with the proposal of the Municipal Engineer and of Dr. Simpson, that the night-soil and sewage should be raised by means of compressed air ejectors, the conditions being in his opinion, not applicable to such a system of sewerage, as it would be impossible to deal with the existing drains without admitting considerable volumes of rainfall if the present

polution of watercourses was to cease, and under these circumstances in times of rain the quantity of liquid in addition to the dry weather flow would be quite prohibitive.

From the information supplied by the Municipal Engineer, Mr. Midgley Taylor found that the present water supply was six million gallons per day, and that when the new reservoirs under construction were brought into operation the amount would be doubled. He considered that the requirements of the City would be met if nine million gallons per day of the total water supply were assumed to reach the sewers and, for the rainfall, that if arrangements were made for two-and-a-half times the dry weather flow, *i.e.*, 31½ million gallons per day in all.

Mr. Midgley Taylor states that in a town situated as Singapore the cheapest and most effectual method of disposing of the sewage is by discharging it direct into the sea in its crude condition, provided a suitable point of disposal could be found in fast running tidal waters. But looking to the existing conditions he decided it would be necessary to separate the whole of the sludge and other solid matters in the sewage, and to subject the liquid part to an oxidisation process before allowing it to flow to the sea.

After consultation with the Municipal Engineer, he decided that the most suitable place for the purification works was a site lying to the South and West of the Buona Vista Road in a small valley between Pasir Panjang Road and the Labrador Heights. The site for the pumping station, he recommended, should be on the lowest land available near the junction of the Keppel Road Diversion, and the Cantonment Road. The plant, to consist of centrifugal twin series pumps driven by triple expansion condensing pattern steam engines, divided into four units of 1,000 cubic feet per minute and two of 500 cubic feet. The maximum amount of sewage to be raised, to be at the rate of 31½ million gallons per 24 hours or 3,500 cubic feet per minute.

Mr. Midgley Taylor proposed a main sewer traversing the entire length of the city from north-east to south-west, and discharging

into the pumping station above referred to. This main sewer would gradually enlarge from 15″ at its summit and, passing under the Singapore River by means of a syphon, attain to the size of 4′-4″ × 6′-6″ at the pumping station.

The construction of the main sewer, he pointed out, would be a work of considerable difficulty, owing to the subsoil, and certain sections would probably have to be constructed in tunnel, which would involve the employment of an air lock and cast iron construction.

The construction of the branch sewers over the City presented camparatively little trouble, and was not gone into in detail in the report.

The sewage on its arrival at the pumping station would be first passed through detritus pits in duplicate, and then through screens automatically cleansed by rakes driven by electricity.

The size of the rising main conveying the sewage from the pumping station to the purification works was recommended to be 54″ in diameter, but on account of the great cost of conveyance of cast iron pipes of so large a diameter, Mr. Midgley Taylor recommended two pipes, one of 41″ and the other of 38″ diameter.

The purification works were to be covered settling tanks, and a single series of percolation bacteria beds, the settling tanks to be constructed to their full ultimate size at the outset, and having a capacity of 4½ million gallons. The liquid, on leaving the tanks, would be passed through the percolation beds to be constructed 9′-0″ in depth with a capacity of 60,000 cubic yards of material, and covering an area of 4 acres. The effluent from these works, to be discharged into the sea through an outfall pipe 3′-6″ in diameter and ending 938 feet from the foreshore into 6′-0″ of water at lowtide.

As regards the collection of night-soil, Mr. Midgley Taylor agreed with the Municipal Engineer's report of February, 1914, and stated that for many years such collection would be necessary, in fact until the whole of the Chinese and Native quarters of the city could be provided with back lanes, and back drainage.

For the purpose of keeping the upper length of the sewers clean during periods of dry weather, Mr. Midgley Taylor stated it would be necessary to construct flushing tanks at the heads of such sewers. These tanks would be provided with automatic discharge syphons, and could be conveniently fed by the salt water scheme. In addition to the flushing tanks, he recommended the admittance of sea water into the main sewer at high-water at convenient points. As it was only proposed to admit into the sewers during periods of heavy rainfall so much of the storm water as the road side drains could carry, it was suggested that storm overflows into the sea at several points should be constructed, these overflows to be at a level just above high-water mark ordinary spring tides and provided with non-return flap valves.

The whole of the sewers were to be provided with efficient means of ventilation by the erection of columns placed at intervals not more than 400 yards apart, and the covers of all manholes throughout the system were to be of a closed air tight type. Where houses of sufficient height exist arrangements were to be made for carrying ventilating shafts up the sides of the house to discharge into the atmosphere above roof level.

Mr. Midgley Taylor also recommended the establishment of a considerable number of latrines in suitable positions all over the City, these latrines to be of the trough closet type and provided with ample means of flushing.

For the district eastward of the Kalang River, which it was anticipated would shortly develop, Mr. Midgley Taylor proposed a subsidiary pumping station, which would lift the sewage into the head of the main sewer.

The estimate for the whole scheme amounted to £538,000, without supervision charges.

In a memorandum, dated 29th of October 1910, Mr. Peirce stated that he was of opinion that an alternative scheme might be prepared and introduced within a shorter period than that required for Mr. Midgley Taylor's scheme. After considering this memo-

randum, the Commissioners passed the following resolution on the 9th of December of that year :—

"That the Municipal Engineer be instructed to prepare esti-
"mates for the installation of a preliminary sewage scheme
"on the plan outlined by him, such scheme to be capable of
"being ultimately made part of a more extended scheme."

Mr. Peirce proposed to alter the proposed site of the purification works. He stated that during the construction of the Alexandria Road Incinerator it occurred to him "that the adjacent valley "would be a most suitable site for the sewage works, inasmuch "as it is low-lying, far removed from dwellings, both the hillsides "being occupied by graveyards, the valley itself being a most "insanitary one, capable of improvement at no great expenses by "efficient drainage and the Commissioners had recently purchased "a large area of land, part of which might be used for the sewage "works in addition to the establishment of incinerators."

He also stated that Mr. Midgley Taylor's proposal for deep sewers gave him grave concern, inasmuch as the subsoil water was only 3 or 4 feet below the ground surface, and that the city was for the most part practically afloat on liquid mud, and any interference with that by pumping would mean serious risk to adjacent buildings. He proposed therefore to divide the city into several drainage areas, each capable of being undertaken independently of the other and to extend the disposal works as required.

The city to be divided into two divisions : (*a*) the area comprising the north of the Singapore River ; (*b*) the area comprising the south of the Singapore River.

(*a*) to be sub-divided into three districts :—

(1) Between the Singapore River and the Stamford Canal.

(2) Between the Stamford Canal and the Rochore Canal (and later described as the Central Division).

(3) The district north of the Rochore Canal.

Area (1) to be drained to a pumping station near the foot of Fort Canning at the junction of River Valley Road and Hill Street.

Area (2) to be drained to a pumping station on the vacant ground at the junction of Becoolen Street and Albert Street and to which would be attached a night-soil depot.

Area (3) Owing to its sparse population not to be at present provided with sewers, the nightsoil from the population of this area to be conveyed to the pumping station in No. 2 district.

A nightsoil depot to be also constructed at the pumping station South Division (Peoples Park) and at Kreta Ayer.

Sewers to be laid at once in areas 1 and 2, North Division, and in a large portion of the South Division.

Mr. Peirce disagreed with Mr. Midgley Taylor regarding the total provision to be made in the sewers, but agreed with the figure of 9 million gallons per diem of dry weather flow. He considered that the provision for storm-water allowed for was too high, and reduced the amount to a total of 18 million gallons in all per 24 hours. (In the works carried out it appears that the sewers are capable of carrying 31½ million gallons per 24 hours, the figure decided on by Mr. Midgley Taylor.) At the disposal works he proposed to construct tanks and percolating filters for the thorough purification of the sewage, but in the first instance, for only 1 million gallons, afterwards to be increased as might be required, (this figure, however, in the works actually carried out, seems to have been much increased) the effluent to be discharged into the Singapore River at all states of the tide.

Mr. Peirce submitted three estimates :—

(*a*) A complete scheme amounting to $4,128,300 (£490,000) with an annual amount for upkeep of $85,000.

(*b*) The scheme outlined in his report for immediate construction $1,313,400 with an annual upkeep of $32,000.

(*c*) An additional cost at a later date for the sewering of the Sultan Ali Estate $240,000.

Work in estimate (*b*) was recommended to be carried out at once and was sanctioned by the Municipal Commissioners.

Plate No. 84 shews the work proposed in estimate (*b*), and gives the divisions and the positions of the pumping stations.

Plate No. 85 is a general plan of the purification works.

Main sewers have been laid to deal with an ultimate maximum wet weather flow of 32,582,600 gallons per 24 hours, providing for a dry weather flow of 9,000,000 gallons per day, the balance being rainfall.

South Division.—The South Division main sewers are $2\frac{1}{2}$ miles long and vary from 9″ cast iron to 45″ diameter concrete. They are laid on a bad foundation of blue muddy clay, steel sheet piles being used during construction, to avoid damage to adjacent houses. The depth in parts was over 20′-0″ and mostly below tide level.

Central Division.—The Central Division main sewers are $1\frac{1}{2}$ miles long, and vary from 9″ diameter stoneware pipes to 30″ diameter cast iron pipes.

North Division.—The North Division main sewers are 1 mile in length and 9″ to 36″ diameter cast iron pipes.

Intercepting Chambers.—Automatic intercepting chambers have been constructed to admit surface drainage from roadside channels, operating by means of an automatic valve or a floating teak ball. These chambers admit 1·25 times the average dry weather flow of the open surface water drains into the sewers.

Pumping Stations.

South Division.—The pumping station at People's Park is built in faced brickwork and plaster, and comprises a screen house with 2 sets of electrically driven screens and dredgers, an office and stores, an engine room with 2 sets of 8″ diameter Stereophagus pumps direct, driven by two 55 B.H.P. motors, and two 15″ diameter Gwynne's centrifugal pumps rope driven from two 150 B.H.P. Diesel engines. Storage has been provided for 60 tons of oil fuel. An automatic electric alarm has also been installed, and control pump wells have been constructed in order to isolate any

unit. The main pump well is 14′-3″ wide × 84′-0″ long × 25′-9″ deep. The lift, including friction, will eventually be about 78′-0″.

Nightsoil Depot.—Adjoining the pumping station is a night-soil depôt 29′-0″ × 27′-6″ with an elliptical reinforced concrete roof 2″ thick and a span of 29′-0″.

Here the night-soil pails are brought in motor wagons and tipped through concrete hoppers into the main pump well. The pails are then washed, disinfected, and brought on a trolley to a collecting shed, where the wagons, after cleaning, collect them.

House Drainage.—Work is proceeding installing a 'squatting' type of W.C. pan in houses in the insanitary areas, in conjunction with the cutting of back lanes through the middle of back to back house property. A 9″ diameter stoneware rider sewer is laid in the back lane to take these connections.

Central Division.—The pumping station in River Valley Road consists of a screen house containing 2 sets of electrically driven screens and dredgers, an office and stores, and engine room which will contain two 6″ diameter electrically driven Stereophagus pumps, each capable of delivering 325 gallons per minute against a head of 65 feet, and a provision for a 7″ centrifugal pump driven by a 46 B.H.P. gas engine, to discharge 1,000 gallons per minute.

North Division.—The pumping station in Waterloo Street has not yet been proceeded with, but will be very similar to the South and Central Stations.

Rising Mains.

The rising main consists of 1,059′-0″ of 24″ diameter cast iron main and 7,267′-0″ of 33″ diameter cast iron main from the South Division (People's Park) pumping station, with junctions for a 15″ diameter cast iron and steel main 2,496′-0″ long from the Central Station ; an 18″ diameter cast iron and steel main 8,659′-0″ long from the Northern Station is still to be laid. These mains will be duplicated subsequently.

There are five Bridge crossings.

Sewage Disposal Works.

The works are situated 3 miles inland on a swampy site about 40 acres in extent, with accommodation for 12 detritus tanks, 64 "Emscher" sedimentation tanks, 51 bacterial filters, 10 humus tanks and 16 sludge beds. The present scheme, to deal with $2\frac{1}{2}$ million gallons per day, comprises the following works :—

Detritus Tanks.—The rising main discharges into an inlet bay 10′-0″diameter, and thence into a 7′-6″wide main feed channel where nightsoil pails, brought from the suburban residential districts, are tipped through hoppers. The sewage then passes through a bar screen with $1\frac{1}{2}$″ spaces, into 3 reinforced concrete tanks, each 58′-0″×5′-3″×average depth 7′-6″. The filtering medium at the bottom consists of 4″ of $\frac{1}{8}$″ gauge clinker, 4″ of $\frac{1}{2}$″ gauge clinker and 6″ of 3″ gauge broken bricks. The tanks are worked alternately for a week each, when they are emptied through a 6″ diameter open jointed stoneware sub-drain into a sump, and thence to a surface water drain. The tanks deal with half the dry weather flow from the South Division and have a capacity of 14,274 gallons each, and with a flow of 1·13 feet per second. From here the sewage passes into a 7′-6″ wide main feed channel and thence through 16 sedimentation tanks of the Emscher type with a sedimentation capacity of 2 hours dry weather flow, arranged in pairs ; the tanks are in reinforced concrete each 26′-6″ diameter by 30′-6″ deep. The channel flowing through the tank consists of a V shaped wooden trough 13′-0″ deep by 10′-0″ wide running the full length of each pair of tanks, and with a capacity of 15,320 gallons each tank. The sludge capacity of each tank is calculated at 43,722 gallons and the total capacity of each tank 86,534 gallons. The sludge is emptied through an 8″ diameter vertical cast iron pipe by the head of water above the outlet. 2″ diameter lead water flushing pipes perforated with 3′-16″ diameter holes at 18″ centres are placed round the tank bottom, to stir up any clogging sludge, and a 1″ diameter galvanized wrought iron pipe to flush the 8″ sludge outlet pipe. The sewage enters and leaves each pair of tanks through

a 3′-6″ wide sluice, over a 10′-0″ wide weir with 4 sluices, each 1′-6″ wide—2″ wooden scum boards are also provided. Outlets for the escape of gas are left in the tank coverings by expanded metal combings. 80% reduction of the suspended solids has so far been obtained.

Sludge Beds.—The sludge will be discharged into 18″ wide concrete channels and gravitate to 16 sludge beds, each 100′-0″ long by 15′-0″ wide with a capacity for sludge to a depth of 2′-0″. The partition walls are made of 2″ planks between 4″ diameter piles. The media consists of 4″ of sand and 8″ of clinker broken to $\frac{3}{4}$″ gauge. The beds are under drained with 4″ pipes discharging into a surface water drain. To permit of the easy flow of the sludge the surface of the beds have a fall of 9″ towards the outlet. The beds have an extreme capacity of six months storage, or 39% of the total sludge-area-capacity of the tanks.

The effluent from the sedimentation tanks passes through a screening chamber (in duplicate) 30′-0″ long by 10′-0″ wide, with a vertical screen 30′-0″of horizontal screens and a 36″diameter screen over the outlet, all of $\frac{1}{4}$″ mesh galvanized wrought iron netting. The feed to the filters consists of 36″ diameter cast iron pipes, with 9″ diameter cast iron branch feeds to the filters.

Filters.—The filters are 10 in number, each 100′-6″ diameter semi-enclosed by brick walls. The total area is 9,562 square yards. The medium consists of coral brought over in blocks from the adjacent islands and broken *in situ*. The total depth of medium is 6·92′ made up of 6″, 3″, $1\frac{1}{2}$″, and $\frac{3}{4}$″ gauge, the total contents being 23,100 cubic yards. The floor of the filters is a reinforced concrete mattress sloping 6″ to opposite sides, and the false floor consists of 2 layers of honeycombed brickwork with $1\frac{1}{2}$″ spaces. The revolving distributors are of the Ham Baker-Candy-Whittaker Type, 100′-0″ diameter with semi-automatic cleaning apparatus for arms, and each capable of discharging 338 gallons per cubic yard per 24 hours with a maximum head of 3 feet. The normal rate of dosing 106 gallons per cubic yard per 24 hours.

Humus Tanks.—The effluent from the percolating filters gravitates along open concrete channels to 3 humus tanks in re-inforced concrete each 120′-0″ long by 30′-0″ wide by an average depth of 4′-10″.

These tanks empty through 9″ diameter cast iron pipes into a concrete chamber, whence the humus will be ejected by compressed air to sludge beds. Screens, the full width of each tank and 6 feet wide, have been constructed of honeycombed brickwork filled in with 1½″ gauge coral and clinker medium. One screen is placed at the inlet to No. 1 tank, one in the centre of No. 2 tank, and one at the outlet to No. 3 tank.

Outfall Channel.—The outfall channel is 160′-0″ long by 15′-0″ wide in reinforced concrete, and discharges through a V notch gauging weir into the Singapore River 3 miles from its estuary.

All the works were carried out in very bad ground, in some cases on 40 feet of black mud, and piling and mattressing were largely resorted to.

The amount spent on the works up to October 31st, 1915, $1,323,677 (£154,458).

The author is much indebted to Mr. Midgley Taylor for the information kindly given from his report to the Municipal Commissioner of the 29th July 1910, and to Mr. R. Peirce for the description of the works carried out by him.

CHAPTER XVIII.

Drainage of George Town, Penang.

George Town is situated on the Island of Penang, just off the West Coast of the Malay Peninsula, and is built on a Cape, as its Malay name of Tandjong implies, it is roughly triangular in shape, two sides being bounded by the sea and one side by the mountains which rise to a height of about 2,700 feet.

The population of the town is about 107,000 persons, more than half of whom are of various Chinese races. There is also a large proportion of the Indian people and a smaller number of the original Malays. In addition to these there are representatives of practically every race in Asia and Polynesia as well as Europeans.

The average rainfall is 112 inches and is of the usual tropical nature with heavy thunder-storms and rains, the effect of which is accentuated by the close proximity of the mountains. Rainfalls at the rate of 1 inch per hour are fairly frequent and an even faster rate is not unusual.

The site of the town is on a flat alluvial plain with a slight fall from the foot of the hills to the sea, a great part of it is not more than two or three feet above high water level spring tides. The rise and fall of spring tides is about 10 feet, but during neap tides the water level remains practically stationary for several days at about half tide level.

In former years, a large amount of flooding took place and the lower stories of European, Chinese, and Indian dwellings were often flooded for days together. The Malay houses being built upon piles did not suffer in this way.

In the closely built upon areas it was considered advisable to take means to stop the flooding of the houses entirely, while in the

suburban districts it was considered sufficient if floods could be carried off within the 24 hours.

The flooding in the town was also accentuated by the fact that a number of main roads, more or less in embankment and with large side ditches, radiated from the town to the suburbs, the general fall being from the country towards the town. The main drainage of these areas followed the roads and so largely increased the amount of flood water to be dealt with in the lower districts.

As a first step to check flooding, intercepting channels were constructed across the general line of drainage above referred to and so arranged as to intercept the flood water flowing from the suburbs towards the town and lead it by shorter routes to the sea. In forming these channels, advantage is taken of a number of cross roads constructed in embankment to form one side of the channel and divert the flood water. The channels are constructed partly in concrete and brickwork and partly in earth. In the suburban districts it was not considered advisable to incur the expense of constructing them large enough to entirely prevent flooding. In these districts they are therefore of a size large enough to deal with about $\frac{1}{3}$rd inch of rainfall per hour. The result has been fairly satisfactory and a great improvement upon former years. A small amount of flooding however still occurs as might be expected.

In the closely built upon areas the main drains are made large enough to discharge 1 inch of rainfall per hour. This figure is found to be about sufficient for heavy rainstorms. No doubt the rain often falls at a faster rate, but a certain amount is absorbed by the ground or otherwise retarded in its flow, and the floor level of new houses are now kept above ground level so that flooding in such cases is rare. In 1909 however during exceptionally heavy rains the run off amounted to about 4 inches of rain per hour for a few hours.

The cost of pumping for surface drainage would be excessive and is not justifiable at present. The drains are given the best

fall practicable having regard to the quantity of water to be dealt with, and the sea level and any deposit is swept down or lifted out by coolies employed for the purpose. Fœcal matter is not admitted to these drains and the garbage is lifted out and sent to the Refuse Destructor and burnt.

The Surface Water Drainage System is therefore only called upon to remove the waste water from houses and rainfall, and is not of a very foul character.

From time to time schemes have been proposed to deal with nightsoil and sullage water by a water carriage system. The first was made by Mr. Robert Peirce, M. Inst. C.E., the late Municipal Engineer in 1893. His scheme was based on the Shone system and followed the lines of Rangoon. Partly for financial reasons and partly owing to some defects which had occurred in Rangoon this was not adopted. A drainage scheme on different lines was placed before the Commissioners in 1912 but again was not adopted.

Failing a proper water carriage system it was decided to adopt the pail system which has the advantage of simplicity and since 1895 this has been in operation.

Under this system latrines are built behind each house. The seat has a recess below for the pail so arranged that it is practically impossible to place it in the wrong position. The pails are of a standard size, and are regularly changed by Municipal vans, the foul pail being taken away and replaced by a clean one with a little disinfectant in the bottom. The foul pails are covered by a lid and removed in closed vans to a depôt on the outskirts of the town where they are emptied and washed ready for re-use. Formerly they were emptied into special boats and the nightsoil taken away for use as manure on cocoanut plantations, but in 1907 the Commissioners decided to pump this nightsoil and suitable pumps supplied by Messrs. Glenfield & Kennedy of Kilmarnock were erected and a rising cast iron main laid from the depôt to an outlet tank constructed in the sea near low water mark close to a deep sea channel and well away from the shore. This outlet tank is

constructed somewhat on the same lines as the Septic Tank in Bombay and elsewhere and retains the bulk of the solid matter while the liquid flows into the sea and is quickly dissipated. Dilution water is added at the depôt by pumping down brackish water taken from the river.

Water closets have been installed in a number of Municipal coolie quarters built in a locality where it was possible to drain to a Stereophagus Pump fixed at the bottom of a suitable well near the nightsoil depôt. It is found that after a little experience ordinary coolies can be taught to use water closets and no difficulty has arisen under this head. The coolies are mostly low class Indians, Chinese, Japanese, &c. The water closets are similar to the later type in use in England but adopted to the squatting attitude.

Some of the European Clubs have been drained with pipe sewers discharging directly into the sea.

An up-to-date water carriage system should be adopted as soon as finance renders it possible and if first installed in the schools and better class houses, the knowledge of how to use the water closets would soon penetrate to all classes and no undue trouble from blockage would arise. Its first cost would be considerable but the annual cost would be less than at present even after allowing for interest and sinking fund while from a sanitary standpoint there can be no comparison.

Steam power generated at the Municipal Refuse Destructor is partly used for pumping nightsoil but in the main the pumping is done by electric power which was installed before steam from this source was available.

The author is much indebted for all the above to Mr. L. M. Bell, M. Inst. C.E., Municipal Engineer of George Town, Penang.

CHAPTER XIX.

Drainage of Shanghai.

SHANGHAI is by far the most important of all the Treaty Ports of China. It may be divided into three areas :—

(i) The Native City (*i.e.*, within the City wall) which has an area of one square mile and a population of 110,000.

(ii) The French Settlement (adjoining the Native City) which has an area of about half a square mile.

(iii) The International or Foreign Settlement which has an area of $8\frac{3}{4}$ square miles and a population of over 450,000 Chinese and 11,000 Europeans, excluding the shipping population.

The present articles deals only with the International or Foreign Settlement, but the description may be considered as applicable also to the French Settlement, although the Native City, in regard to drainage and other Municipal matters, occupies no better position than that of an ordinary Chinese town of several centuries ago.

Shanghai is situated on the River Whangpoo, 14 miles above its junction with the Yangtszekiang. The normal rise and fall of the tide is about 11 feet. The water is fresh and highly charged with suspended matter, mostly of an alluvial nature.

The country both in the Settlement and for miles around is very flat, the substratum consisting of an alluvial deposit. The general ground level of the Settlement is only about 2 feet above High Water Mark, Ordinary Spring Tide, and the undeveloped portions and the surrounding country are intersected by numerous tidal creeks, which are utilized as far as possible as sewer outfalls.

The rainfall in Shanghai averages 43·60 inches per annum, the variations of which are shewn in the following table :—

SICCAWEI OBSERVATORY.

INCHES OF RAINFALL.

1873—1902.

	Max.	Min.	Mean.	Mean Temperature.
				F.
January	7·77	0·03	2·15	37·4
February	4·25	0·00	2·29	39·2
March	6·00	0·59	3·21	46·2
April	9·43	0·92	3·57	56·5
May	7·17	1·11	3·60	65·5
June	19·37	0·74	6·66	73·4
July	11·63	0·12	5·10	80·6
August	13·52	0·49	5·94	80·2
September	10·79	0·78	4·72	72·7
October	11·79	0·31	3·31	63·3
November	5·93	0·10	1·85	52·0
December	3·64	0·14	1·18	42·1
Inches .	62·53	27·92	43·60	59·2
			Range ..	43·2

June is pre-eminently the rainy month, both for frequency and abundance. In June, 1875, there was a rainfall of 19·27 inches in twenty-one days.

The devotion of the Chinese to agricultural pursuits points to the solution of the economical disposal of the ordure of the Settlement and the Municipal Council derives a net income of Tls. 47,770 (£7,000) therefrom, a native contractor paying that sum for the right of collecting night-soil in the Settlement. This contractor provides all labour and covered receptacles for the collection, and is under bond to convey it in boats to rural districts without causing nuisance in the Settlement. The system works well and the whole of the night-soil is removed daily before 9 A.M. Water closets are prohibited under the local bye-laws, but urinals and

slop-water sinks are connected with the sewers. Owing to the numerous outlets provided by the natural creeks there are no large main outfall sewers, the largest being 3′-0″ × 2′-0″. Tidal flap valves are not used, and the tide is left free to circulate through the sewers whose inclination (owing to the flatness of the district) rarely exceeds 1 in 500. Wherever possible, dead ends are avoided, in order that the tidal water may circulate through the various systems.

The majority of the roads (of which there are 87 miles) are macadamised, and consequently a large amount of detritus finds its way to the street gullies, which are also emptied periodically.

Complaints as to emanations from the gullies are practically non-existent.

Rigid supervision is maintained over all private drainage works and no drains are allowed to be covered until they have been inspected and approved by the Council's Inspectors.

Owing to the difficulty of obtaining stoneware pipes at a reasonable cost, the Council in 1891 decided to manufacture its own pipes of concrete, and these pipes are used for all Municipal work, and also supplied to private individuals. Within the last three or four years, all pipes up to 12″ diameter have been made by machine, and compare favourably for porosity and durability with glazed stoneware pipes. They are made of the usual pattern in 2-feet lengths with spigot and socket joints. Other pipes of the following standard sizes are also manufactured :—

Circular, 2′ and 3′ diameter.
Oval, 2′-3″ × 1′-6″ and 3′ × 2′.

These are all reinforced by iron rods. Street gullies of the usual pot form are also made.

Wherever new roads are made through country districts, where the rateable value does not justify the laying of a sewer, the drainage is effected by means of a ditch, 10 feet wide on the top and 6 feet deep, cut on one side of the road. When such districts get built up, these ditches are filled in and sewers laid in the ordinary manner.

The water-supply of the Settlement is in the hands of the Shanghai Waterworks Company, Limited, and the supply is drawn from the Whangpoo River, about two miles below the town. The water is drawn off at high tide and goes through a process of settling tanks and sand filters. The quality of the water is excellent, as may be seen from the following analysis by the Health Officer :—

Sample received, 25th November 1905.

Report sent out, 30th November 1905.

Sample.—Shanghai Waterworks Co.'s water.

Physical Characters—Pale yellowish green colour with slight opacity.

	Parts per 10,000
Solid matters in Solution	15·0
(*a*) Volatile	7·0
(*b*) Fixed	8·0
Appearance on ignition, slight charring—	
Total hardness	11·0
(*a*) Temporary	5·0
(*b*) Permanent	6·0
Chlorine	2·7
Nitrogen as Nitrates	0·03
Saline Ammonia	0·02
Albuminoid Ammonia	0·015
Poisonous Metals	*Nil.*
Nitrates	*Nil.*
Phosphates	*Nil.*
Sulphates	Traces.

Bacteriological Examination.—Nutrient gelatine plates incubated at 23° C shewed 200 micro-organisms per cubic centimetre. The ratio of liquefying to non-liquefying organisms was one to ten.

Agar plates incubated at blood heat yielded 40 microbes per cubic centimetre.

Report on Analysis.—A sample of well filtered water shewing a high degree of chemical and bacteriological purity.

The author is indebted for the above interesting notes to Mr. Charles Mayne, M.I.C.E., the Engineer and Surveyor to the Shanghai Municipal Council.

APPENDIX.

INTRODUCTION.

In this Appendix an entirely new and up-to-date set of Specifications are given which the Author considers may be of use to young Engineers.

They consist of Specifications for Pneumatic Ejectors and Tubbing, Iron and Cast Steel, Brickwork, Masonry, Woodwork and Painting.

Sufficient information for Specifications for stoneware pipes, cement and concrete is given in Part I and it is not necessary to recapitulate it here. A note is also given on the principle of working of the Venturi meter which it is hoped may be useful, and a comparative note on the cost of the drainage per head of population of various cities and towns is given and a note on sewage pumping and finally a glossary of terms for the use of students.

SPECIFICATIONS.

Pneumatic Ejectors and Tubbing.

1. The contractor shall provide and erect at the various sites ejector stations of cast-iron tubbing, each to contain sewage ejectors operated by compressed air, of the sizes and numbers given.

2. The contractor shall provide and fix at each ejector station a tubbing in accordance with drawings, and of the internal diameter specified for each particular station. The tubbing shall consist of the necessary concrete and brickwork, cast-iron plates, segments, and entrance shaft with a cast-iron cover. The plates and segments shall be joined with rust or lead joints and coated with Dr. Angus Smith's composition. The tubbing shall be perfectly watertight and provided with all necessary steel girders, perforated cast-iron plates $\frac{3}{4}$ inch thick for platforms and floors, a wrought-iron ladder, a compressed air pipe for supplying fresh air, and a cast-iron entrance manhole cover. A brass number plate having the number of the ejector station cast or engraved thereon shall also be provided and fixed to the tubbing in a position visible from the top when the entrance cover is removed.

3. Inside the tubbing, duplicate compressed air sewage ejectors of the sizes and numbers specified shall be provided. The ejectors shall be spherical in shape, of cast-iron up to and including 250 gallons discharging capacity and of wrought-steel for all sizes above. All the ejector work shall be thoroughly coated with Dr. Angus Smith's composition.

4. The inlet and outlet pipe connections of each ejector shall

be of such a diameter that the velocity of sewage through them shall not exceed four feet per second when filling and discharging once a minute. The minimum diameter of these connections shall be 6 inches. The outlet orifice shall be placed at the bottom of the ejector body providing a perfect washout, so that all silt or solids falling to the bottom shall be ejected at the commencement of each discharge.

5. Flap valves to inlet and outlet pipe connections shall be provided and fixed close to the body of each ejector. These flap valves shall have slightly larger areas than the inlet and outlet pipe connections, and shall be constructed of cast-steel faced with leather or dermatine, held in position by wrought-steel plates and delta metal studs and nuts, arranged for easy replacement when necessary, and attached to the seating with gunmetal hinges and spins. The inspection covers for these valves shall be provided with a $\frac{3}{4}$ inch diameter eye bolt on all ejectors of 200 gallons capacity and above.

6. Sluice valves of an approved design and make shall be provided and fixed on the inlet and outlet pipes to ejectors, as near as possible to the horizontal mains on both inlet and delivery sides.

These valves shall have strong cast-iron bodies and doors each with four gunmetal faces, two on the body and two on the valve door. They shall be fitted with bronze screwed spindles and gunmetal nuts. The stuffing boxes and glands shall be bushed with gunmetal, and the valves shall be fitted with suitable handwheels.

7. Each ejector shall be fitted with an automatic air supply and exhaust valve, having a cast-iron body, with gunmetal liners and piston.

A suitable lubricating arrangement shall be provided on each valve for keeping the piston leathers well greased and soft. The lubricator reservoirs shall contain sufficient oil to last not less than one week.

8. The automatic valves shall be of the size shown in the following table :—

Capacity of each Ejector.	Diameter of automatic air valve.
Gallons.	Inches.
50	1½
100	1½
150	1½
200	2½
250	3
300	3½
500	4
750	5

9. The automatic valves shall be placed as high as possible in the entrance shafts to the ejector stations. At the base of each pipe connecting the automatic valves to the ejectors, a receptacle shall be fixed containing a perforated brass screen to prevent corks, matches, and other buoyant substances being carried up into the automatic valves from inside the ejector body.

10. Each pair of ejectors shall be fitted with a Shone and Ault's alternating valve, with cast-iron body and gunmetal liners and piston. The alternating valve is provided in order to prevent the two or three ejectors from discharging simultaneously.

11. Both the automatic and alternating valves shall be actuated by the rise and fall of the sewage in the ejectors, by cup and bell floats, actuating a small D slide valve. The D slide valve and seating shall be of gunmetal, and the cup and bell floats shall be connected together by phosphor bronze rods. The upper bell rod passing through the top of the ejector shall be of phosphor bronze working through a woodite gland bush. The gland plate shall have an oil cup cast on to keep the woodite bush soft and pliable.

12. A slide valve drip tray 12 inches square by 2 inches deep shall be fixed on top of each ejector, to catch oil and water out of the exhaust ports of the valve box.

13. The pipe connections from the slide valves to the automatic valves shall be made on the top sides of the automatic valves

to facilitate lubrication. The slide valve boxes and columns shall be fastened to ejectors with studs or bolts.

14. The air main connections shall enter the tubbing as near the road or surface level as possible, and all openings in the tubbing shall be made perfectly watertight. These connections shall extend one clear foot from the outer face of the tubbing.

15. A stop valve shall be supplied and fitted to the air main connection inside the ejector tubbing and one on each ejector connection. Between the air main and alternating valve a screening chamber shall be provided with a flanged lid or cover bolted on and fitted with a perforated brass plate.

16. The delivery pipes to the sealed sewage main shall pass straight up through the cone roof of the ejector tubbing or entrance shafts, and not through the side plates.

17. A reflux valve and sluice valve, both of approved design and manufacture, shall be provided on the delivery pipe, arranged in a concrete and brick chamber. The delivery pipe shall terminate in a flanged or socket joint at least one foot clear of the outer face of the valve chamber. The chamber shall be constructed in unexcavated or undisturbed ground, and as near the ejector tubbing as possible.

18. Each ejector shall be provided with a six-figure counter of approved design and make complete with all attachments for automatically registering the number of discharges of the ejector.

19. Each ejector shall be fitted with a pressure gauge of an approved type fixed with suitable connection to the top of the ejector body.

20. The exhaust air pipes from the ejectors shall be supplied and laid complete and connected to the cast iron pipes connecting the inlet manhole and air filters, and fitted with aspirator nozzles to assist the ventilation of the gravitation sewers.

21. Each ejector station shall be provided with a suitable hand pump, fixed inside the tubbing for discharging water from the bottom of the tubbing to the inlet manhole. These shall be fitted

with all necessary suction and delivery pipes and connections and shall be arranged to draw from a small sump to be provided for the purpose in the concrete at the bottom of the tubbing.

Iron and Cast Steel.

1. All cast-iron must be tough and of even grain. The castings must be sound, sharp, straight and true, even in thickness and carefully trimmed, free from air holes, flaws and all other imperfections, and must not be stopped or plugged. The metal used must have an ultimate tensil strength of not less than 9 tons per square inch. A test bar 1 inch wide by 2 inches deep in section and 36 inches long, made from the same running as any casting must not, when supported at two points 36 inches apart and locked at the centre, break under a less load than 30 cwt. nor until the deflection amounts to 0-3 inch. A like bar similarly supported must be capable of sustaining a load at the centre of 28 cwt. for a consecutive period of 24 hours at the least. A suitably shaped tensil test bar, having a sectional area of two square inches, must be capable of sustaining a tensil strain of 14 tons for a consecutive period of 24 hours.

2. All cast-iron pipes must, unless otherwise specified, be spigot and socket pipes. They must be cast vertically in dry sand moulds, the socket end downwards, with a sufficient head on the spigot end of each pipe, the head being subsequently cut off by suitable machinery. They must be uniform bore and thickness of metal throughout. From each running there must be supplied six bars of each of the types described in the last preceding clause. All pipes must be tested at the manufacturer's works by means of hydraulic pressure of not less than 150 lbs. per square inch.

3. All cast-iron pipes must, after being well cleansed and trimmed, be heated to a temperature of 300° F. (150° C.) and carefully coated internally and externally according to Dr. Angus Smith's process. All rust must be removed before the coating applied.

4. The Engineer or his Representative may examine all cast-iron pipes and fittings on the works, with callipers or other instruments, in order to ascertain the thickness of metal throughout them. He may also select any pipes or fittings and require them to be ripped open. Should any pipe or fitting so selected and ripped open be found to be in every respect in accordance with the specification the loss entailed thereby shall be borne by the Government but if it should be found defective in any respect the loss shall be borne by the Contractor and the Engineer or his Representative shall be entitled to select another pipe or similar fitting to be ripped open without the Government's being responsible for the loss entailed even though it should be found not to be defective.

5. All malleable cast-iron must be thoroughly annealed, the annealing penetrating to a depth of at least $\frac{1}{16}$ of an inch. All articles made of a malleable cast-iron must be capable of being reduced in breadth by least 25 per cent. without cracking. Articles may be selected for testing upon the site of the works, under the conditions prescribed in the last preceding clause as to the selection of cast-iron pipes and fittings, for ripping open.

6. All wrought-iron must be tough, fibrous and uniform in character. The tensile strength of the metal must be not less than 22 tons per square inch. The contraction of the area of the cross section at the point of fracture must be not less than 25 per cent. and the elongation in a length of 8 inches must be not less than 20 per cent.

7. All wrought-iron must be free from burnings, blisters, cracks, and all other imperfections. No piece shall be welded save so far as may be necessary in order to make up a length greater than can ordinarily be obtained in the market. Welding, when permitted, must be sound and workmanlike. All screws, bolts, straps and small articles of wrought-iron must be dipped in or coated with raw linseed oil. All straps and collars must be shrunk on, if required, so as to make them firm and tight.

8. All rivet-holes must be drilled. All rivets must be firmly clinched whilst hot and left with a neat clean segmental head free from cracks and flaws. All bolts must have well shaped heads which must have a level bearing on the surface against which they abut ; when they rest on a curved surface, they must be shaped to the same curve and accurately fitted.

9. Screws must be cut to Whitworth Standard, without taper, clean and true, with a full deep thread. The holes in the nuts must be tapped to the proper size, so as to fit the bolt accurately.

10. All steel castings must be thoroughly annealed and free from all defects, no stopping, plugging, patching, burning or electric welding being allowed without the sanction of the Engineer or his Representative.

11. The metal must have an ultimate tensile strength of not more than 35 tons nor less than 28 tons per square inch with an elongation of 15 per cent. in two inches, and a bar 1 inch square must be capable of being bent cold, without fracture, through an angle of 60° over a radius not greater than $1\frac{3}{8}$ inches.

12. All steel forgings must be of steel made by the Siemens Martin process, and must be mild, ductile and free from all blemishes, shuts or hammer marks. Strips must be cut from the principal forgings for analysis and testing. The tensile strength must be not less than 27 tons per square inch with an elongation of 25 per cent. in 8 inches.

13. All steel used in the manufacture of steel joists must have a tensile strength of 28 to 32 tons per square inch with an elongation of not less than 20 per cent. in 8 inches and a reduction of area of not less than 40 per cent. at the point of fracture.

14. All joists must be supplied of the sections specified, the margin allowed above or below the dimensions and weights specified in no case exceeding $2\frac{1}{2}$ per cent.

Brick-Work.

1. All bricks must be hard, sound, of good quality, well and uniformly burnt, of even colour, square, with straight sharp arises, ringing well when struck with a hammer and free from fire and other cracks. They must be uniform in size.

After immersion in water for 24 hours they must not absorb a greater weight of water than 15 per cent. of their dry weight. Their resistance to crushing must be not less than 88 lbs. per square centimetre.

2. All brick-work must be of the best description and workmanship. No broken bricks must be used in it except as closures. All bricks must be immersed in water for at least two hours before being used. The bricks must be evenly and truly laid, breaking joint course by course and properly bonded together in every part. The bond must be English unless otherwise specified. In arches, vaulting and other circular work they must be so laid as to fit the curvature of the centres and templates as nearly as possible without cutting, unless otherwise specified. The joints must be close and regular, in no case exceeding 0·01 metre in thickness, except where, in the back joints of circular work a thicker joint may be unavoidable.

3. The Schedule Rates for brick-work in walling shall also be applicable to brick-work in nogging, and in arches of all radii and shapes.

Masonry.

1. All stone must, except as otherwise specified, be of the best quality procurable for the purpose for which it is intended and must be obtained from quarries in the neighbourhood approved by the Engineer. No stone must be used which contains vents or flaws, or which is traversed by seams of perishable material or is brown or quarry-faced or in any way otherwise defective. The Engineer or his Representative may condemn and order the re-

moval from the works of any stone which, in his opinion, is unfit for the work or does not come up to the approved samples.

2. All faces of stones required to be dressed must be true and out of winding, except where otherwise specified. In stone specified as in hammer dressed the face must, as far as possible, be squared and levelled with a mason's hammer by knocking off all protuberances and ridges. Where it is specified as very rough, rough, or medium dressed, the protuberances and ridges must be further reduced with a chisel, leaving the face truly level, though rough with depressions. The depressions must not be more than 0·01 metre in depth of 0·001 square metre in area in the case of very rough dressed faces, nor more than 0·005 metre in depth or 0·0005 square metre in area in the case of rough dressed faces, nor more than 0·004 metre in depth or 0·0001 square metre in area in the case of medium dressed faces. In fair dressing, the face must be dressed fine, but the chisel marks may be left visible in a few minute dimples scattered over it. In fine dressing neither chisel marks nor any dimples whatever must be left in the face.

3. Cut-stone work must be worked to such sizes and shapes as are shown in the drawings or may be ordered by the Engineer or his Representative. Unless otherwise specified, the stone must be fair-dressed on face and joints, and rough dressed, on beds, full true and out of winding. All visible edges and angles must be free from unsightly chippings. The joints must be close and must not exceed 0·005 metre in thickness. No stone must be less in any dimension than the height of the course. All projecting stones must tail and bed back into the work at least twice the length of the entire projection and not less than one and a half times the height of the stone. Cut-stone work must, if so required by the Engineer or his Representative, be clamped or dowelled with copper clamps or dowels.

4. Rubble masonry must be composed generally of large stones weighing about 66 lbs. clean, flat-bedded properly selected for their places, and carefully laid with a suitable proportion of smaller stones

and chips to fill up the interstices. The whole must be hand-set and solidly bedded in and surrounded with mortar on every unexposed side. There must be no hollows or dry portions in the work, nor pinnings in the face. The face stones must tail back and bond well into the body of the wall, and must not be of a height greater than either the breadth or face or the length of the tail. Through stones covering the whole width or thickness of the walls, must be inserted at every one metre measured horizontally and vertically. The rate for rubble masonry shall include the cost of the through stones. The faces of the walls must be strictly straight, and either plumb or regularly battered as the drawings may show or the case may require. Except where otherwise specified the quoins must be rough-dressed on top and bottom beds and faces, and the cost of the same shall be included in the rate for rubble masonry.

5. The conditions above contained as to rubble masonry shall apply to rubble masonry in random courses, except that in the latter, all faces must be rough-dressed, the joints must be of a parallel width not exceeding 0·006 metre, and all the face stones must be of nearly equal size.

6. Dry rubble packing must consist of a layer of uniform thickness of stone rubble carefully set on ground properly formed for the purpose. The stones must be laid on their largest face. The interstices between the rubble stones must be filled up with stone chips and the whole packing made compact.

7. Dry stone pitching must consist of stones of good, hard and durable quality. The stones must be of an average weight of 110 lbs. at the least, no stones being in any case used which are less than 66 lbs. in weight. They must be carefully and neatly laid by hand to the slopes and sections shown in the drawings or to such slopes and sections as the Engineer or his Representative may order, their greatest length being, so far as possible, at right angles to the face of the pitching. Except at the face, the interstices between the stone must be carefully packed with smaller pieces of broken stone to be obtained by the accidental or inten-

tional breakage of the larger stones brought for use in the work, but so that the volume of such smaller stones shall in no case exceed 10 per cent. of the work. At the face of the pitching, the stones must fit together so that no joint exceeds one centimetre in breadth, the sides of the stones being sufficiently dressed for the purpose. The faces must be hammer dressed.

Wood-Work.

1. All wood must be of the best quality, well seasoned and free from shakes, large, loose, or dead knots, bursts, sun-cracks, flaws and imperfections of every kind.

2. All wood-work must be of the best description and workmanship, and if after erection any undue shrinkage or bad workmanship appears, the Engineer shall have power to remove the defective work and replace it. All exposed arises must be either chamfered or beaded as may be required by the Engineer or his Representative. Boarding wherever required must be grooved and tongued and beaded, and the boards must not be more than 0·15 metre in width, including the tongue. The ends of all timber bedded in masonry must have a space left on both sides and at the ends so as to give the air free circulation around it. All timber resting on or bedded in masonry buried in earth or hidden from view in any way must, unless otherwise specified, be well tarred with boiling coal tar.

Painting.

1. All paint must be mixed to the satisfaction of the Engineer or his Representative, and must be free from skins and all impurities. Each coat shall, if required, be an entirely different colour. Each coat must be rubbed down with sand paper or pumice before the next is applied.

2. No paint must be applied during, or immediately after wet or damp weather, or while the surface of timber or metal work to be painted is wet or damp and an interval of at least 48 hours

must elapse before each application. Each coat must be quite dry before the next is commenced.

3. Timber-work must first be cleaned and must then receive a coat of linseed oil and be knotted, primed, and stopped with putty. It must then be painted with three coats of the best white lead, white zinc, or other approved paint, finishing with approved tints.

4. All tenons, mortises, joints, butting surfaces, and all timber which, when fixed, will be inaccessible for painting must before being fixed in position receive two coats of white lead or other approved paint. All bolt heads, washers, nuts, straps and all other approved iron-work in timber structures must be finished with two coats of black metallic paint except where otherwise specified.

5. All iron and steel-work must, before leaving the manufacturer's yard, be scraped and cleaned and must, after inspection, receive a coat of boiled oil, oxide of iron or other approved paint as directed.

6. Machined surfaces must be coated with white lead and tallow properly mixed.

7. The whole of the metal work must, when in position, be thoroughly scraped and brushed and washed clean with fresh water, to the satisfaction of the Engineer or his Representative. All places where rust spots show must then be chipped and rubbed and must receive a coat of thin paint before the application of the priming coat over the whole surface. The whole of the work must then receive a priming coat and two additional coats of paint finished in such a colour as may be directed by the Engineer or his Representative.

8. All surfaces of iron-work, including bolts, which, when fixed, will be inaccessible for painting, must, after cleaning, receive a priming coat and, with the exception of the bolts, two additional coats of approved paint before being placed in position.

9. If so directed by the Engineer or his Representative, iron or other work shall be coated with a paint composed of bitumen and benzine oil in the proportion of 56 lbs. of bitumen to 5 gallons of benzine oil. The bitumen must be the best pure, refined, natural Trinidad bitumen, drawn from the upper part of the Refining Tank. It must be obtained from the Lake proper on the Island of Trinidad and must be free from cinders, earthy matter and all other impurities. The bitumen must be melted in a suitable vessel over a slow fire, thoroughly stirred and allowed to cool slightly before the benzine is added. When mixed and before use the liquid must be strained through a wire gauze strainer of 400 meshes to the square inch (62 meshes to the square centimetre) and, if not immediately required, must be kept from the air in hermetically sealed tins until wanted. The paint must be applied in three coats in the ordinary way, unless otherwise ordered.

The Venturi Meter.

The Venturi Meter is a contrivance for measuring the flow of a fluid through a pipe and depends for its action on the fact that in a steadily moving stream of fluid, moving in an enclosed channel of varying sections, the sum of the energy due to the pressure and also that due to the velocity is constant for any section of the stream.

In its simplest form the Venturi Meter consists of two truncated conical pipes connected together at their smaller ends by a short cylindrical pipe. The velocity of flow of an incompressible fluid passing the varying sections of the cones will be exactly in inverse ratio to these sections, and from the above Law of Hydraulics, the energy due to the velocity will therefore be in direct ratio to the sections of the cones. If therefore suitable pressure gauges are attached to two sections of the cones where the area of the stream is known the pressures can be ascertained and the velocities through these sections can be computed. The quantity of fluid

flowing through the pipe is known if the velocity through any particular section is known.

The law connecting the pressures at two points of a pipe of varying sections with the velocities at those points is termed the "Venturi Law," and is equally true for all fluids, whether incompressible liquids or gases; but in the question of gases, since the factors of initial pressure, and expansion due to temperature, affect the results, these items must be allowed for in all calculations.

The Venturi Meter is usually provided with a self-recording apparatus which indicates by means of dials the quantity of fluid passed in a given time, which quantity can be expressed in any convenient units. It is also provided with a mechanism which records on a drum rotated by clock-work a curve showing the rate of flow at any instant.

The recording mechanism is actuated by the usual pressure taken from the two points in the pipe conveying the fluid to be measured. This elevates or depresses columns of liquid (usually mercury or water) which, by suitable floats, puts in motion a chain of clock-wheels and cams which convert the expression of the ratio between the two pressures into terms of quantity of fluid passing through the pipe. In the case of a gas meter this gearing is rather complicated, as in addition to the ratio between the pressure exerted by the fluid, the absolute pressure and also the temperature of the gas must be taken into account. These three factors are separately transmitted through a differential gearing to a cam in a form of logarithmic spiral, which, by adding the three varying units, forms the necessary process of multiplication and gives the correct reading on the recording instrument.

The above short description of the Venturi Meter is given for the information of young Engineers and Students who possibly have little knowledge or experience of this useful contrivance and the Author hopes it may be of value to them.

Note on the Cost of Drainage Schemes.

The following Table has been compiled because the Author believes that Engineers connected with drainage schemes feel the greatest interest in knowing how their particular scheme stands in point of cost as compared with other cities.

The schemes of which the cost is given are largely those that the Author has some personal knowledge of. Generally they are on the "separate system", and the cost is calculated on prospective populations. The figures quoted must not be taken as absolutely correct. The actual or final cost is very difficult to ascertain as many works not strictly chargeable to the scheme are often included, as for instance public conveniences, and night-soil depôts, and in the case of sewage farms it is doubtful whether such can be properly included in the cost of a scheme. On the other hand earlier and existing sewers, the cost of which is not included, are often utilized when a complete scheme is carried out.

The British schemes are generally more expensive than those on the Continent or further afield.

London, the largest city in the world, is, considering its success, and the millions it serves, an economical scheme. It was constructed when little was known of drainage, and it may be looked upon as a pioneer scheme. It was designed by Sir J. W. Bazalgette upwards of 50 years ago and few alterations have been made in later years from his original idea; it stands as a monument to that great Engineer. Unfortunately Sir J. W. Bazalgette did not live to see the completion, and the work was continued by Sir Alexander Binnie, and later by Sir Maurice Fitzmaurice, C.M.G.

The scheme was originally designed to deal with a total population of 7 millions; it is now practically complete and deals with a population of 5½ millions.

Birmingham and Manchester are inland cities and have schemes of great merit. They have had many difficulties to contend with, and their respective officials have done much to solve the problem of the inland disposal of sewage.

Glasgow is one of the most recent and successful large schemes in the United Kingdom, and is undoubtedly economical and is very much on the lines of London.

Douglas (Isle of Man) is principally known for its adoption of the "Adams Sewage Lift" described in Chapter I, which is an automatic arrangement by which the high level sewage is made use of to lift the low-level sewage.

Berlin is probably the most up-to-date scheme on the Continent and is not expensive when this is taken into account.

Cairo and Port Said, considering the flatness of the areas on which they are built, and the sectional pumping necessary, must be considered as economical schemes. In Cairo the Sewage Farm is 16 miles from the centre of the city, and in both schemes the farms are included in the cost.

It is interesting to note the economy of the schemes in the East and the Far East, and more especially in India. India is now largely a self-contained country; there are few materials needed for drainage which it cannot itself supply, and labour, though increasing in cost, is still very cheap.

Bombay stands out as a model of cheapness, for the cost given includes at least two pumping stations replaced by up-to-date machinery, and in a large area of the city complete house connections have been done at the cost of the Corporation.

A word of praise must also be given to Calcutta, with its cost of £1-2-0 per head, despite its large area, which includes the suburbs on the West bank of the river Hooghly.

Madras will probably run Bombay very closely. It has fourteen pumping stations, but it is not possible as yet, to give the final cost, as the work is not completed.

The extraordinary cheapness of Lucknow and Mirzapur is principally due to its system of open surface drains, and to the large population of its Bazaars in a confined area, but this method of drainage is only applicable to towns having a small water supply per head.

Singapore is still under construction and the cost given will probably be reduced.

Sydney and Melbourne are amongst the most expensive schemes in the world. In 1880, when Sydney was designed, its population was 427,000, and on that population the cost amounts to £9-10-0 per head. But it is said to be designed for a prospective population of 1,200,000, and should that number ever be reached the cost will be reduced to £3-8-0 per head. The present population is 725,400. The construction owing to the necessity for tunnelling and bridging was very costly. All sewage works in Australia are naturally costly, owing to the high cost of the long sea carriage of imported materials, added to the expensive labour, etc., and the same would apply to South American schemes.

Name of City or Town.	Separate or Combined System.	Pumping or Gravitation.	Disposal.	Cost per head of population. £ s. d.	Remarks.
London	Combined ..	Pumping ..	River Outfall	2 5 0	Settlement of solids by chemical treatment. Sludge barged out to sea.
Liverpool	Do. ..	Do. ..	Bacterical treatment and River Outfall.	3 19 0	
Birmingham	Separate ..	Do. ..	Partly River and Partly Sewage Farm.	2 10 0	Bacterial treatment.
Manchester	Partly Separate .	Do. ..	Discharged into Manchester Ship Canal.	2 3 0	Bacterial Purification.
Glasgow	Combined ..	Do. ..	River Outfall	2 12 0	Settlement of solids after chemical treatment. Sludge barged out to sea.
Douglas (Isle of Man) ..	Separate ..	Gravitation with Adams Lift.	Sea Outfall	2 10 0	On average Winter and Summer population.
Berlin	Do. ..	Pumping ..	Sewage Farm	2 17 0	Bacterial treatment.
Hamburgh	Do. ..	Do. ..	River Outfall	2 7 0	Do.
Paris	Do. ..	Do. ..	Sewage Farm	2 2 0	No treatment.
Cairo	Separate and Combined.	Do. ..	Do.	2 1 0	Principally Compressed Air Pumping. Bacterial treatment.
Port Said	Do. ..	Do. ..	Do.	2 5 0	Bacterial treatment.

Calcutta	Combined	Do.	River Outfall	1 2 0	No treatment.
Bombay	Separate	Partly Gravitation and Pneumatic Ejectors for low levels. All sewage pumped at Outfall.	Sea Outfall	0 16 6	Practically complete.
Madras	Do.	Pumping	Sewage Farm	0 18 0	Not yet completed.
Karachi	Do.	Compressed Air Pumping.	Do.	1 4 0	No treatment.
Benares	Do.	Pumping	River Outfall	2 0 0	Do.
Lucknow	Do.	Gravitation by open surface drainage.	Do.	0 9 0	Bacterial treatment.
Mirzapur	Do.	Do.	Do.	0 11 0	Do.
Singapore	Do.	Pumping	Sea Outfall after Bacterial treatment.	3 10 0	Not yet completed.
Sydney	Partly Separate	Do.	Three Main Collectors, one discharging into sea, the others pumping to Sewage Farm.	9 10 0 (see explanatory note.)	Partly Bacterial treatment.
Melbourne	Combined	Do.	Sewage Farm	10 15 0	Do.
Buenos Aires	Do.	Do.	River Outfall	5 5 0	No treatment.

Note on Sewage Pumping.

The Author has been helped in compiling the following note by an Authority on Sewage Pumps whose name stands in the first rank of Engineers who specialise in this branch of Engineering.

Sewage Pumping involves many special questions and considerations in respect to the design, arrangement, and type of Plant best suited for each particular case. The conditions of working are so varied and numerous, that it is very difficult to make a general statement recommending any particular form of Plant. Especially is this the case in late years, as, apart altogether from the conditions in respect to the quality of the sewage, depth below the surface, and height of lift, there have been added to the many forms of Steam Engines employed other types of Prime Movers, *e.g.*, Oil Engines, Gas Engines, and Electric Motors, all of which have more or less good reasons for their adoption.

The chief classes of pumps in use at the present time consist of vertical and horizontal plunger pumps, centrifugal pumps, and ejectors using compressed air.

In pumping sewage, it is necessary that the sewage should be thoroughly screened, especially if the pumps are of small size.

The only pump that will deal with unscreened sewage is that in which compressed air is used in pneumatic ejectors, in all other cases screens should be used.

The principal points to be considered in laying down a pumping plant to deal with sewage may be enumerated in the order of their importance as follows :—

(*a*) Reliability in working.
(*b*) Mechanical efficiency.
(*c*) Fuel consumption.
(*d*) Maintenance.
(*e*) Accessibility, in view of repairs, cleaning, &c.
(*f*) Simplicity in mechanical details.
(*g*) Variation in respect to capacity within wide limits.

(*h*) Automatic stopping and starting.

(*i*) First cost.

In designing a plant, the water-end or pump has first to be considered, the application or choice of the Prime Mover being usually considered for a different set of conditions to that of the pump.

In most instances reciprocating pumps, having one or more externally-packed plungers working vertically through the top of the plunger chamber, have been found to be the best form of pump, and they meet the greater number of, and to a large extent, all the above stated features. In some cases, however, where the lift is low, and the sewage comparatively free from solids, sand or refuse, centrifugal pumps have also been largely employed.

They have not been altogether a success, especially in small units, where the passages through the pumps and the impellers are usually so limited that they choke, and considerable difficulty is experienced in clearing them.

Again, owing to the high speeds at which the various parts operate, the impellers wear rapidly and their efficiency falls in consequence.

The most desirable pumps for handling sewage are those in a vertical position. Grit and other suspended matters fall away from the working faces, and avoid the rapid wear of the parts.

Different means may be employed for driving both plunger and centrifugal pumps. The selection of the most suitable will entirely depend upon local circumstances, and the size of the units intended to be supplied.

An electric drive is usually the most expensive, as current can seldom be obtained at a rate per unit which permits of economical working.

Considerations in respect to the best Prime Mover to be employed in different parts of the world, have also a great bearing on the choice as to which of these two types of pump is the best from an engineering and commercial point of view.

The following table gives the mechanical over-all efficiency, both for reciprocating plunger pumps, and centrifugal pumps, the figures have been based on a large number of cases and they give a close approximation of what may be expected for each pump, of the type and drive specified, with plants of the size of 100 horse power, more or less :—

CLASS OF PUMP.	Motive Power (Vertical or Horizontal.)	Type of Drive.	Overall Efficiency.
Vertical Triplex Plunger.	Gas Oil Engine ..	Single Spur Gear ..	62%
Do. ..	Do. ..	Belt and Single Spur Gear.	58%
Do. ..	Rotative Steam Engine.	Direct	85%
Do. ..	Do ..	Single Spur Gear ..	75%
Do. ..	Do. ..	Belt and Single Spur Gear.	70%
Do. ..	Electric Motor ..	Double Spur Gear ..	66%
Vertical Duplex Plunger.	Duplex Steam Engine "Worthington".	Direct	90%
Centrifugal ..	Gas or Oil Engine ..	Belt	51%
Do. ..	Steam Engine ..	Do.	58%
Do. ..	Do. ..	Direct	65%
Do. ..	Electric Motor ..	Do.	63%

It often occurs in laying out a system of sewage pumping for a town that certain areas are below the intended main sewer levels. It is then convenient to use pneumatic ejectors to deal with the sewage from these areas from which they lift and discharge the sewage at the most convenient point into the main sewer. Their efficiency is low, and the reasons for employing them are due to their flexibility and simplicity, and to their operating automatically.

In considering the whole question of sewage pumping, it may be safely asserted that there are conditions for the useful employ-

ment of the various forms of pumps, driving gear, and motive power, depending principally upon the size of the units, and their location, which latter is in most cases fixed by conditions due to the level and position in which the plant can be installed relatively to the sewage to be dealt with.

Experience has proved that externally-packed Plunger Pumps are the most trustworthy ; and as regards the motive power, steam engines are the most efficient, and cheapest in working and first cost for large powers at Main Pumping Stations, but there are other considerations apart from these governing the choice of the motive power in the case of subsidiary stations which are more or less peculiar to each set of conditions in different cases.

Glossary of Terms.

IN all works on Engineering, and more particularly in these days of specialized branches of Engineering, many technical terms and names are used which are not usually found in Dictionaries. It is, therefore, deemed desirable, for the information more particularly of students interested in the special subjects with which this work deals, to give the meaning of such terms. Some are peculiar to certain districts in India, an example being *nahani*, a washing place, another name for which is *mori*,—a word which is to a greater extent used outside the Bombay Presidency than within it. Certain it is that the meaning of many of the names used, though familiar to Sanitary Engineers in the East, would be quite unknown to Engineers practising in Europe; and therefore the Author hopes that this Glossary may be useful, not only to students interested in Sanitary Engineering, but even to Engineers generally. If some of the terms seem to be too simple and well-known to require definition, it should be remembered that English is a foreign language to many Eastern students, and it is to them that this work is also addressed.

ADJUTAGE .. .. Helper. The name given to a lip on the top of the inner leg of an automatic siphon, which helps the siphon to start flushing by allowing the water to fall over without touching the side of the leg.

AERATION .. .. Impregnation with air or gas.

AEROBIC .. .. "Living in contact with air." The term is applied to certain micro-organisms which live preferably in the presence of atmos-

pheric oxygen and oxidize the ammonia in sewage into nitrites and nitrates. Aerobes are divided into facultative and obligate aerobes : the former can live in the absence of oxygen, the latter are unable to do so.

ALLUVIAL .. .. The term applied to the soil and miscellaneous substances collected and deposited by the action of water.

ANAEROBIC .. .. "Living without air." The term is applied to certain micro-organisms which live preferably without air, and reduce the organic matter in sewage, thus preparing it for treatment by aerobic bacteria.

ANNULAR .. .. Having the form of a ring, pertaining to a ring.

ANTI-SIPHONAGE PIPE. The term given to a small pipe which supplies air to siphons and traps, and prevents their being untrapped by a partial vacuum being formed through a sudden rush of water falling in a pipe to which the siphon or trap is connected.

ARGILLACEOUS STONE. The class of stone in which alumina or clay is the characteristic constituent, such as slate and shale.

ARRIS .. .. Edge : a term often applied to bricks ; for instance, it should be specified that bricks should have good sharp arrises, *i.e.*, sharp edges.

AUTOMATIC .. .. Having the power of self-motion ; that which is self-moving, self-acting.

BACTERIA .. .. Bacteria is a generic term applied to a number of minute unicellular organisms belonging to the vegetable kingdom which

multiply by fission only. The scientific term including all members of this group is Schizo mycetes or Fission-fungi. In this book the word bacteria is used generically to include micrococci and other members of this family.

BAFFLE WALL .. A wall built in a tank or channel to check the velocity of the flow.

BASALTIC .. .. A term applied to any substance derived from basalt—rock of volcanic origin.

BIOLOGICAL TANK .. A receptacle for liquid so constructed as to furnish to the micro-organisms contained therein the conditions most favourable to the efficient performance of health work in the direction of sewage purification.

BOARD OF CONSERVANCY. The body of men appointed to carry out measures for the preservation of their and cleanliness within a certain district.

BONING ROD .. A T-shaped piece of timber of a certain length, used in checking the levels of excavations or pipes.

BRIQUETTE .. .. A name derived from the French "Brique," a brick, and applied in Engineering to a small brick, made generally for testing purposes, as in cement testing.

BY-PASS .. .. An auxiliary passage by the side of a conduit or pipe.

CALCAREOUS STONE . The class of stone in which carbonate of lime predominates, such as marbles, lime stones, etc.

CAMBER .. .. A slight convexity or arching given to a road cross-wise to allow the surface water to drain off readily.

CAPACITY .. .. The quantity which a vessel is capable of containing or a channel of discharging. In case of sewers, the capacity is equal to the area of the sewer multiplied by the velocity.

CATCH-PIT .. .. A chamber built below the level of the invert of a sewer in which the velocity of the flow is reduced so as to collect such heavy deposit as may be in the sewage.

CENTRING .. The framing of timber by which an arch is supported during its erection.

CESSPOOL .. .. A receptacle for sewage: a chamber built to receive and temporarily hold sewage until it can be removed.

CHAIN-PUMP.. .. A pump consisting in one of its simplest forms of an endless chain equipped with a series of disks, passing downwards into the water and returning upwards through a tube.

CLINKER .. .. The incombustible portion of coal, partially fused, which forms in grates and furnaces.

COMBINED SYSTEM . The name given to the system of sewerage in which the conduits are constructed for the double purpose of receiving both sewage and surface water.

CONFIGURATION .. The external aspect or contour of the land or district.

DASH-POT .. .. An apparatus for preventing the too sudden movement of parts. It usually consists of a small cylinder filled with oil and fitted with a piston through which a minute hole is drilled. The piston rod is attached to the part to be controlled.

DATUM .. .. Some fact or quantity granted or known from which other facts or quantities are calculated, *e.g.*, a certain step at the Town Hall, Bombay, is assumed to be 100 feet above an imaginary plane for the purpose of calculating other levels in the City.

DECANTATION .. The act of pouring from one vessel to another, so as to separate one part of the liquid from another or to separate the liquid itself with matter in suspension from matter precipitated in it, such as clay from sand, by putting the mixture into the water in a vessel, stirring it, and then pouring it off into another vessel, the liquid thus poured off carrying away the lighter particles of clay.

DEODORIZE .. .. To deprive anything of the fetid odour resulting from impurities.

DHAPA .. .. A slab stone used for covering or spanning a masonry drain.

DHOBI GHAT .. A public place used for washing clothes and sometimes belonging to and under the supervision of the local authority.

DIAPHRAGM .. .. *Vide* "Parda."

DISK-VALVE .. .. A circular sliding iron door used for closing a pipe sewer.

DOMESTIC SEWAGE . The sewage derived from the habitations of man and beast in contradistinction to that derived from factories.

DOUBLE DISK .. Two round blocks made principally of wood, fixed twelve inches apart and connected by bolts—an arrangement for passing through pipe sewers to cleanse the same.

DROP PIPE .. .. A vertical pipe joining two sewers at different levels in a manhole.

DRY SYSTEM LATRINE. A privy where fæcal matter and sullage are temporarily collected and afterwards removed by hand.

EJECTOR .. .. The name given by Mr. Shone to a spherically-ended container for receiving sewage, from which it is ejected by compressed air.

EXTRADOS .. .. The name given to the outside curve of an arch.

FAUCET .. .. That end of a pipe which is enlarged to receive thespig ot end of another pipe to make a joint.

FILLET .. .. See "Splayed."

FLAP-VALVE .. A broad shutter made of wood or metal and hung over the face of a sewer and falling by its own weight and completely closing the sewer.

FLUSHING DOOR .. A flap which is let down by a hinge and closed over the face of a sewer or conduit to detain the sewage or liquid behind it, which, when opened, allows the liquid to flow away with a rush.

FÆCES .. .. The solid matter excreted by human beings: night-soil.

FOOT RESTS .. .. Raised surfaces in latrines or urinals to place the feet on, thus marking the exact place for the feet when either standing or squatting upon.

FORESHORE .. .. The sloping part of the sea shore between high and low tides.

GAMEL .. .. An iron pan for carrying materials generally of a semi-liquid nature, such as mortar.

GASKET .. .. A thin twisted or plaited rope of hemp put first into the joints of pipes to prevent the cementing material from passing through into the pipes.

GHANI .. .. An Indian term for a mill used in grinding mortar, the motive power being usually bullocks or buffaloes.

GRADIENT .. .. The name give in Sanitary Engineering to the inclination or slope of a pipe or conduit: the horizontal distance divided by the vertical fall.

GRAVITATION .. The act of tending to a centre of attraction as when water flows from a higher to a lower level.

GROUT .. .. Cement mixed with water to the consistency of cream.

GULLY, GALI OR HOUSE-GULLY. A name given to a narrow open passage between houses, also called a sweepers' passage, as it affords access to sweepers and *halalkhores* to the latrines or privies of the house.

HALALKHORE .. A class of people employed to remove by hand fæces, etc., from privies and dry system latrines.

HAUNCHES .. .. A term applied to the middle part between the crown and spring of an arch. In a semi-circular drain between the sewer and the side wall and the circular part of the drain.

HIGH-LANDS .. The name given to lands above highwater spring tides.

HUMID .. .. Moist, damp.

HUMOUS OR HUMUS. Vegetable mould, or the matter deposited in a biological tank or filter.

HYDRAULIC .. .. A term relating to the conveyance of water through pipes or channels.

HYDRAULIC LIME .. The term applied to lime which will set in the presence of water.

HYDRAULIC MEAN DEPTH. The Quotient obtained by dividing the area of the cross section occupied by the liquid by the wetted perimeter.

INLET .. .. The term applied to the higher or upper end of a pipe or conduit.

INSPECTION CHAMBER. A masonry chamber built to facilitate the inspection of a drain.

INTERCEPTING TRAP . A trap or siphon placed on a house drain between the sewer and the house to intercept and prevent gas from the former passing up the drain or into the house.

INTRADOS .. .. The name given to the inner curve of an arch.

INVERT .. .. The name given to the lowest portion of a sewer, pipe, or drain.

JAGGERY .. .. Coarse brown (or almost black) sugar made from the juice of sugarcane or the sap of various palms, often seen in the form on small round cakes.

JOWAR .. .. Indian name for millet.

JUMP-WEIR .. .. A name given to an arrangement, made at the street end of a house-gully, which permits of a small flow of sullage from the gully to fall into a trap in connection with the house drain, but allows of a greater flow of surface water to pass over and discharge into a drain set apart for the purpose.

KANKAR .. .. A class of hydraulic lime-stone, composed mostly of carbonate of lime, but also containing an admixture of clay and sand.

KHANKI .. .. A stone fair-dressed on the face and rough-dressed on the other sides, fixed at the edge of a road boarding on an open drain, or used as facing in a stone building.

KURBI .. .. Hindustani name for Indian corn or maize.

LAKH .. .. One hundred thousand.

LATRINE .. .. A privy, or a place set apart for natural purposes. It may be either on the dry or water carriage system.

LIFTING GEAR .. An arrangement used for the raising or lowering of flushing doors by means of chains.

LIQUEFYING TANK . A tank in which the organic matter of sewage is broken up or liquefied by bacteria.

LOAM .. A species of earth consisting chiefly of rich vegetable mould : a light earth or marl.

LOW-LANDS .. .. The term applied to those lands which are situated below high-water spring tides.

MAGADAMIZE .. To cover a road with small broken stones, which, when consolidated, forms a firm surface. (From Macadam, the Inventor.)

"MALI" .. .. The Indian name for a gardener.

MANHOLE .. .. A masonry chamber built on a sewer or drain, through which it is possible to enter and have access to the sewer or drain for cleaning and inspection purposes.

MICRO-ORGANISMS .. In this book the word may be taken to mean bacteria. See "Bacteria."

MORI .. .. A place prepared with masonry and set apart or used for washing or bathing purposes, either inside or outside a house.

MURAM .. .. A local name given to the stratum of disintegrated rock lying between the clay and basaltic rock.

NAHANI ..	.. See "Mori."
NIGHT-SOIL ..	.. The solid matter excreted by human beings: fæces.
NULLAH OR NALA ..	The Hindustani name for a water-course: a rivulet.
OUTFALL ..	.. The lower end of a sewer or conduit, or localities where the sewage or surface water is finally disposed of.
OUTLET ..	.. The lower end of a sewer or conduit or the end through which the sewage is discharged from a manhole, tank, etc.
OVOID ..	.. A term used to describe sewers built in the shape of an egg.
OXIDATION ..	.. A term used in sewage purification to denote the final change which takes place in destroying organic matter: the addition of oxygen to the effluent by the admission of air to the latter.
PARDA ..	.. The name given to a stone slab fixed in the sides of a surface water gully so as to dip into the water and form a trap.
PATHOGENIC	.. The name given to denote a class of organisms which, when introduced into the body, gives rise to diseases. (Pathogenic; disease producing).
PENSTOCK ..	.. A gate usually made of iron that can be raised or lowered at will to control the discharge of sewage or water.
PLASTIC ..	.. A substance capable of being moulded, used in patent jointed pipes to prevent the cement running into the pipe.
PLINTH ..	.. The masonry base of a building.
PLUMB ..	.. Vertical or straight.

PLUMB-BOB .. .. A weight attached to a string to test the uprightness or verticality of any object.

PNEUMATIC SYSTEM . The system in which vacuum or compressed air is the motive power employed for lifting sewage.

POLING BOARDS .. Boards intended to support the sides of a trench and placed behind the walings.

PRECIPITATION .. The process by which a substance held in suspension in a liquid is made to separate from another or others and fall to the bottom.

PRIVY .. .. A latrine.

PUBLIC CONVENIENCES. Places set apart for the convenience of the public, such as latrines, urinals, washing places, dhobi ghats, cab stands.

PUDDLE .. .. Clay worked up by being mixed with water to a plastic or sticking condition.

PUMICE STONE .. A porous stony substance of volcanic origin.

PUNNED .. .. Rammed: packed tight by pounding.

RENDERED .. .. Made smooth: plastered in cement.

ROAD DETRITUS .. The term used to denote the small particles of disintegrated stone, etc., worn off from the surface of the roads by traffic.

RUBBLE .. .. Rough irregular stones used in coarse masonry or to fill up between the facing courses of masonry.

SCRAPER, OR SHIELD. An appliance used in cleaning an ovoid sewer and made in the shape of the sewer with a portion of the bottom or the top cut off; when inserted in the sewer it heads up the sewage by contracting the area of the flow, which is consequently accelerated and facilitates cleaning by softening the deposit.

SCREEN	A riddle or sieve used to separate fine matter from coarse, either solid or liquid.
SCUM-BOARD.. ..	A board placed across, and descending six to eighteen inches below the surface of the fluid in a tank, to check the flow and thereby arrest the floating matter.
SEAL	The depth of contained water in a trap which prevents the free passage of air or gas through it.
SECTIONAL SYSTEM .	The name given to the system of sewerage in which a district is divided into sections each of which has sewers gravitating to one point within it.
SEPARATE SYSTEM ..	The name given to a system of sewerage, in which there are different conduits for storm-water and sewage.
SEPTIC	A term denoting the promotion of putrefaction.
SET STONE	A medium dressed stone used for paving purpose in places liable to heavy traffic.
SEWER	A conduit for sewage.
SEWAGE	The filthy liquid containing excrementitious and other matters from houses and towns which passes through drains.
SHORED	Propped or supported by timber.
SIGHT RAILS.. ..	Rails about 4 inches by 2 inches fixed across an excavation on wooden posts with their tops at a certain height above the intended level of the bed of the sewer. A line of sight along the tops of the rails so fixed would be parallel to the gradient of the sewer.

SILICEOUS STONE .. A class of stone in which silica or sand is a characteristic constituent, such as granite, trap, basalt, etc.

SILT .. .. .. A term given to the deposit of solid matter found in sewers and drains.

SIPHON .. .. A vent tube whose legs are of unequal length, used for drawing liquid out of a vessel, the shorter leg being inserted in the liquid and the larger hanging down outside; when the air is sucked from the tube the pressure of the atmosphere causes the liquid to rise in it and flow over.

SIPHONAGE .. .. The action or operation of a siphon.

SLUDGE .. .. Soft mud: the term applied to the deposit in biological tanks and filters.

SLUICE .. .. A contrivance for excluding or admitting the inflow of a body of water.

SOCKET .. .. The opening at the end of a pipe generally enlarged, into which is inserted the end of another pipe to make a joint. See "Spigot."

SOIL PAN .. A receptacle fixed in a latrine or a water-closet, to receive fæcal matter.

SOIL PIPE .. .. A vertical pipe fixed against a wall to take the discharge from water-closets.

SPECIFIC GRAVITY .. The weight of the bulk of any substance compared with that of the same bulk of water.

SPIGOT .. .. The end of a pipe which is inserted into the enlarged end of another pipe to make a joint.

SPLAYED FILLET .. A narrow band of cement used to complete the joint of a pipe and having a sloped surface.

STRATUM .. . .. A layer or bed of stone or earth. Strata (the plural), several such layers superposed above each other.

STERILIZATION .. By the expression sterilization of any substance is meant destruction or removal of all germs and their spores contained in or on such substance.

STREET CONNECTION. That part of the house drain which lies between the street sewer and the boundary of the house.

STOP TAP .. .. The name given to a cock used in connection with a time siphon.

SUBSOIL .. .. The beds or strata which lie below the surface soil.

SULLAGE .. .. The liquid and other matters discharged from bath, cook-room, etc., and not containing excrement.

SUMP .. .. A reservoir or pit below a pump the lowest point.

SURKI .. .. A fine powder made by crushing burnt brick·

TANK GAS .. .. The gas that is liberated in a liquefying tank, while the organic matter of the sewage is broken up or liquefied.

TENSILE STRAIN .. The elongation per unit of length resulting from a tensile stress.

TIDAL-FLAP .. .. A door attached to a sewer at a manhole, by which the sewage may be retained in the sewer for flushing purposes (properly, a gate used to exclude tidalwater)

TRAPPED .. .. So formed as to hold a depth of water sufficient to prevent the free passage of air or gas.

TRADE SEWAGE .. Sewage derived from factories containing chemical matter.

TUBBING .. .. A water-tight cast-iron chamber constructed underground to contain an ejector or ejectors.

TUFA .. .. A light porous rock of volcanic origin.

URBAN .. .. That part of a large city or town which has been fully built upon as opposed to Rural.

VELOCITY .. .. The rate of movement or flow : the distance traversed in a given time, usually expressed in feet per second or per minute.

VENT PIPE .. .. The pipe connected with a sewer or drain to maintain an equilibrium of pressure between the outside air and the inside air of a sewer and to allow of the discharge of the sewer air into the open air, or the admittance of outside air into the sewers.

VENTILATE .. .. To create a current of fresh air through a sewer or drain so as to cleanse it of foul air.

VOUSSOIRS .. .. Wedge-shaped stones or blocks of concrete used in constructing an arch.

WALING .. .. A piece of timber placed horizontally to support the sides of a trench.

WASH-DOWN CLOSET. A latrine on the water carriage system, the soil pan of which discharges downward into the trap.

WASH-OUT CLOSET .. A latrine on the water carriage system, the soil pan of which discharges horizontally into the trap.

WASTE WATER PIPE. A vertical pipe used for the discharge of sullage.

WATER CARRIAGE LATRINE. A privy, the fæces from which are carried to the sewers by water.

WATER-CLOSET .. A latrine on the water carriage system.

WATER GULLY .. A trapped receptacle through which the surface water from the road flows into an underground drain.

WATER TABLES .. Flat dressed stones fixed at the sides of a road over which the surface water from the road flows to the water gully or drain.

WETTED PERIMETER. The length (measured at right angles to the flow) of such parts of the sides and bottom of a conduit or channel as are in contact with the liquid.

WINDSAIL .. .. A tube or funnel of canvas used to convey air into sewers or drains.

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